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ABSTRACT

TITLE OF THESIS: The Breakdown of the PC Paradigm: A Critical Look At Information Display Technology As An Analysis Inhibitor

STUDENT: Steven F. Rue, GySgt USMC

CLASS NO. PGIP 2003 **DATE:** August 2003

THESIS COMMITTEE CHAIR: Mr. Francis J. Hughes

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The Department of Defense (DoD) has come to rely on Commercial-Off-The-Shelf (COTS) acquisition as the primary means to introduce and upgrade computer technologies throughout the military. In adopting this approach, the personal computer (PC), based on a commercial, business-model design, has become a de-facto standard.

Within the thesis, this common, and widely-accepted desktop computer environment is defined as the *PC Paradigm* and encompasses the typical office-suite software, the information display, and the use of the *desktop metaphor* as the user-interface. The author contends that this near-exclusive reliance on COTS technologies is based on market-driven, commercial product solutions rather than a "domain specific" system design that is optimized to support intelligence analysis.

The thesis addresses the following research question: Could the current personal computer environment (characterized as the PC Paradigm) function as an analysis inhibitor, rather than as a tool to facilitate analysis?

A grounded theory approach was utilized in structuring the study. The research draws upon an exhaustive survey of cross-disciplinary literature encompassing applicable research in the fields of cognitive science, graphic design, visualization display

technologies, and human-computer interface design, and seeks linkages and points of intersection between the related fields relevant to the research question.

Key findings suggested that a "paradigm conflict" exists between the needs of intelligence analysis and the commercial, office-based personal computer employing the desktop metaphor as a user interface. Additionally, COTS technology acquisition, and its associated commercial standards, have appeared to supplant a design process optimized for the needs of the intelligence analyst. Such an approach disregards domain specificity in favor of a generalized, "one-size-fits-all" product solution.

NATO perspectives and design initiatives are reviewed and contrasted with current Department of Defense guidance. Key DoD technical architecture documents reveal a conspicuous lack of design guidance regarding human-computer interface issues.

The thesis concludes that the PC Paradigm environment does contribute to inhibited analysis. The current paradigm is not derived from cognitive ergonomic requirements unique to intelligence analysis, nor does it support the analytic methodologies widely regarded as "best practices" within the field. The author contends that domain relevance is lacking in business-model tools when applied to the problems of intelligence analysis.

The thesis provides a unique convergence of concepts and design considerations from disciplines outside the normal scope of the intelligence community, and seeks to provide a synthesis of multidisciplinary research.

Configuration management for cognitive systems is advocated, as well as the further exploration of Cognitive Task Analysis (CTA) methodologies as tools for assessing both proposed and existing analyst support systems.

THE BREAKDOWN OF THE PC-PARADIGM: A CRITICAL LOOK AT INFORMATION DISPLAY TECHNOLOGY AS AN ANALYSIS INHIBITOR.

by

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CONTENTS

Chapter **Page**

CHAPTER 1

PROBLEMATIC PARADIGMS: A CRITICAL LOOK AT CURRENT INFORMATION DISPLAYS AS TOOLS FOR INTELLIGENCE ANALYSIS

COMMERCIAL OFF-THE-SHELF SOLUTIONS: FAST AND FLAWED

Somewhere in the midst of a phenomenon that has been characterized as "the ruthless pursuit of COTS,"[1] intelligence analysis became imperiled. Within the Department of Defense (DoD), commercial-off-the-shelf (or COTS) products have been increasingly seen as the "fast-track" to inject technological solutions into a less-than-nimble procurement system. And while research and development costs and long lead times have indeed been slashed, the wholesale adoption of products created for the commercial market has eroded the military's ability to influence and manage design.

Presently, both DoD and the private sector operate under what the author terms the *PC Paradigm*[2], an environment driven by mass-market imperatives that are based upon a business-model design. This thesis argues that the widespread acceptance of the commonly available desktop PC as an analyst tool is problematic and suggests it can function as an *analysis inhibitor*, masking alternative representations of the data under consideration. Such implications are non-trivial. If "analysis" is regarded as a subset

[1] North Atlantic Treaty Organization, *Commercial Off-the-Shelf Products in Defence Applications "The Ruthless Pursuit of COTS,"* RTO-MP-048 (Neuilly-Sur-Seine Cedex, France: Research and Technology Organization, December 2000), vii. Cited hereafter as NATO, *COTS Study*.

[2] The author's use of the term, *PC-Paradigm*, denotes a "Personal Computer Paradigm" that is used to characterize the conventional, commercially available desktop or laptop personal computer configuration to include its Windows-based *desktop metaphor*. The concept is further elaborated upon within the thesis.

within the *domain of intelligence*, such an effect could potentially create conditions of *analytical domain restriction*, inadvertently guiding and limiting the analyst's thought processes and solution-sets to those facilitated by the tool.

The author contends that the fundamental rift between the use of the personal computer (PC) as an "analytic tool" and its suitability to perform in that role is largely based on failure to employ widely-accepted elements of design; particularly cognitive factors and human-computer interface (HCI) principles. By surrendering to COTS acquisition, DoD has in effect endorsed a *design-by-proxy* philosophy that has transferred responsibility and *thus the design initiative* to private industry, contractors, and vendors.

Current practice closely resembles what has been referred to as *the anticipation and control dilemma*, as articulated in a recent study conducted by the Advanced Science and Technology Policy Planning Network for the European Union:[3]

> At an early stage of technology development, the nature of the technology (and the articulation of interests) are still malleable – but it is unclear what the effects and impacts will be. By the time these become clear, the technology is entrenched and vested interests make it difficult to change the technology.

Such criticism is typically addressed by incremental design changes, hardware upgrades, and the ubiquitous new software release. In actual practice such solutions result in "feature creep" and what has been characterized as "development-by-accumulation."[4] Incrementalism, however, only serves to ornament a fundamentally-flawed design.

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[3] Stefan Kuhlman and others, *Improving Distributed Intelligence in Complex Innovation Systems: Final Report of the Advanced Science and Technology Policy Planning Network (ASTPP)*, Monograph, Fraunhofer Institute (Karlsruhe, Germany: Institute Systems and Innovation Research, June 1999), 42.

[4] Thomas S. Kuhn, *The Structure of Scientific Revolutions*, 3rd ed., (Chicago: The University of Chicago Press, 1996), 2.

In keeping with Kuhn's classic perspectives on the concept of paradigm[5] it is instructive to note, that

> a new theory, however special its range of application, is seldom or never just an increment to what is already known. Its assimilation requires the reconstruction of prior theory and the re-evaluation of prior fact, an intrinsically revolutionary process.[6]

Such revolutionary measures are called for in this study. If the intelligence community is to achieve *analytical dominance* in the face of ever-more-sophisticated adversaries, it will be unlikely to do so equipped with "over-the-counter" COTS technologies. One path towards this goal may be to seek out productive ways in which to capitalize on the *best practices* of multiple domains. Fusing the IC's understanding of the *intelligence domain* with design principles derived from promising research in cognitive science, human-computer interface design, and visualization, could create a revolutionary synthesis. The goal is to *regain design initiative.*

It is hoped that the evidence presented in this study will contribute to the formation of new ideas, provide new linkages among existing data, and illuminate the shortcomings of the current *PC Paradigm*; in short, to "to urge a change in the perception and evaluation of familiar data."[7]

To bring the specific aims of this research into sharp focus, a concise statement of the problem, the research question generated, and evaluative criteria, are stated below.

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[5] The word "paradigm" has various interpretations (even within Kuhn's text) to include "model," "pattern," and "worldview." Kuhn however, explicitly prefers to define the concept as "like an accepted judicial decision in the common law, it is an object for further articulation and specification under new or more stringent conditions." (*The Structure of Scientific Revolutions*, 23.) This definition strikes the precise chord for the contentions advanced in this thesis and is adopted for the purposes of this study.

[6] Kuhn, Thomas S., 7.

[7] Kuhn, Thomas S., x-xi.

A PROBLEM, A QUESTION, A SEARCH FOR ANSWERS

The Problem

As outlined above, Commercial-off-the-shelf (COTS) acquisition practices are the driver for system procurement, providing business-model-based tools that are not suited to the tasks required of intelligence analysts. This environment, referred to in this study as the *PC Paradigm,* is inspired by market forces and is not founded upon design principles that support analysis.

The Research Question

Could the current personal computer environment (characterized as the *PC Paradigm*) function as an *analysis inhibitor*, rather than a tool to facilitate analysis?

Evaluative Criteria

In researching the areas of concern stated above, the following criteria will guide the evaluative process:

1. A theoretical basis for such conditions should exist (or be evident) in the literature, which may be exhibited in one or more of the following ways:
    a. Dissatisfaction with the current paradigm.
    b. Evidence to suggest that analyst tasks may be inadequately supported.
    c. Current model appears to violates/ignore accepted guidelines within cognitive science, human-computer interface (HCI) and graphic design.
2. *Congruency issues* will be apparent. (Discussed in depth in Chapter 2.)

THE PURSUIT OF ANALYTIC RIGOR

As a central "core competency" of the intelligence community (IC), considerable discussion has centered on what constitutes preferred analytic practice. Such debate has been ongoing since the IC's inception and in recent years has been the personal focus of a succession of Directors of Central Intelligence (DCI). Seeking to bolster analytic rigor, a concerted effort was made to establish "implementation of sound analytic standards … ensuring that sufficient attention [was] paid to cognitive challenges in assessing complex issues."[8] A succinct encapsulation of the essence of this school of thought by Deputy Secretary of Defense, Paul Wolfowitz is offered below:[9]

Analysts and their analysis are deemed most useful when they:

- Clarify what is known by laying out the evidence and pointing to cause-and-effect patterns.
- Carefully structure assumptions and argumentation about what is unknown and unknowable.

The very process of hypothesis-generation and seeking "cause and effect patterns" implies that mental modeling and visualization is occurring. This contention is further supported by considerable research in the fields of cognitive science, graphic display, and human-computer interface (HCI) technologies that suggest that considerable overlap exists in theoretical principles and applied design between these areas and intelligence analysis.

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[8] Richards J. Heuer, *Psychology of Intelligence Analysis* (Washington, DC: Center for the Study of Intelligence, 1999), xv.

[9] Jack Davis, "The Challenge of Managing Uncertainty: Paul Wolfowitz on Intelligence-Policy Relations," *Studies in Intelligence* 39, no. 5 (1996): 35.

The brief summary above is offered as a *point of departure* for the further exploration outlined in the thesis which focuses on issues that exist at the intersection of *cognitive science*, *graphic display visualization*, and *intelligence analysis*. This study does not seek to extend the debate surrounding the issues of analytic preferred practice within the IC. The underlying assumptions that frame the author's contentions are defined below.

Tools For The Analyst: Unintended Consequence?

We believe the analyst of tomorrow must be freed from the current tool-centric environment. The analyst must be allowed to focus on problem-solving, not tool sets or questions of where and how data is obtained.

- F.J. Hughes, *The Art and Science of the Process of Intelligence Analysis*

In the pursuit of analysis, as in any endeavor, tools are often used to facilitate the process. Prior to the widespread use of automated systems, such support tools typically consisted of a variety of hardcopy document storage and retrieval methods, matrices, templates, and the "corporate memory" of the intelligence analyst. As information technologies (IT) matured, the evolution of computer-assisted tools that were employed in intelligence analysis mirrored that of the private sector. Computing resources underwent a dramatic shift from centralized mainframes and minicomputer clusters to stand-alone and networked workstations. The personal computer (PC) soon became the dominant paradigm for the infusion of information technology.

Tool Utility: The Matter of Congruency. The shift to PC-based platforms was a pivotal juncture that marked the adoption of the PC, its hardware suite and interfaces – *including its fundamental business-model paradigm* -- as the de-facto standard for DoD

automation. Research is presented that suggests that the market-driven "one-size-fits-all" approach of the PC and its suitability as a tool to support intelligence analysis are in conflict. In assessing the extent and potential impact of such conflict, the concept of *congruency* is explored.

Sometimes referred to as *conformity,* the concept "defines the degree of correspondence between the mental model in the user's mind and the actual system presentation."[10] *Simply stated, does the tool facilitate or inhibit the work it is designed to assist?* This concept has profound implications for intelligence analysis and will be developed and explored in depth.

Visualization as a Tool. Once data is arrayed, either visually or in a mental representation, the mind immediately seeks patterns and assigns meaning based on what it "sees." The effect of the "presentation-as-interpretation" is considerable. "A visual image not only organizes the data at hand in meaningful structures, but is also an important factor guiding the analytical development of a solution."[11] For the intelligence analyst, *data representation* remains secondary to *analytical depth*, and the information display has been offered as a tool to support both efforts.

Some studies have suggested however, that "a display that is good for analysis is one that is bad for visualisation."[12] This is an intriguing prospect and this view, along

[10] North Atlantic Treaty Organization, *Visualisation of Massive Military Datasets: Human Factors, Applications, and Technologies*, RTO-TR-030 (Neuilly-Sur-Seine Cedex, France: Research and Technology Organization, May 2001), 59. Cited hereafter as NATO, *Visualisation Study.*

[11] Efraim Fischbein, *Intuition in Science and Mathematics* (Dordrecht, The Netherlands: Kluwer Academic Publishers, 1987), 104.

[12] NATO, *Visualisation Study*, 84.

with a significant body of work supporting the visualization discussion is examined in depth in Chapter 2.

It is important to discuss visualization in terms of concept and desired end-state, (i.e. "What do we want to achieve?") and not as a critique of specific applications or to weigh the merits of particular systems and schemas under development. The emphasis is placed on *process and goal* and not *product or tool*. Bernsen suggests that "the importance of a vision can be that of providing a model within which we think and create. If the model is outdated, thinking becomes unduly constrained." [13]

Let us then define *visualization* as a conceptual construct, a point on the analysis continuum rather than a deliverable product.

The PC Paradigm: A Worldview Challenged

Both the private-sector and the Department of Defense have come to rely on commercial-off-the-shelf (COTS) products to form their technological base rather than pursuing in-house development. The intent is well-meaning, even if counterproductive. The urge to supply the latest desktop technologies to the workforce is commendable, and standardization greatly facilitates procurement and technical support.

Marketing claims aside, however, there is little or no evidence to support the contention that the process of *intelligence analysis* has been augmented or enhanced by the presence of the PC on every desktop. On the contrary, it has forced DoD in general (and the IC in particular) to function within a business model exemplified by the *desktop*

[13] Niels Ole Bernsen, "Natural Human-Human Computer Interaction," *in Frontiers of Human-Centred Computing, On-Line Communities and Virtual Environments*, ed. Earnshaw and others (Berlin, Germany: Springer Verlag, 2001), 347.

metaphor. The reliance on this widely-accepted configuration will be referred to as the "*PC-Paradigm*."

<u>What Are User-Interface Metaphors and Why Do They Matter</u>? Metaphor can be defined in the linguistic sense as "a figure of speech in which one thing is likened to another; an implied comparison."[14] A *user interface metaphor,* then, serves as a representational linkage between a task that a user wishes to perform and its computational counterpart.

> User interface metaphors map familiar source concepts to abstract, computational target domains. For example, the well-known *desktop metaphor* introduced by Xerox and popularized by Apple allows users to understand the operating system of a computer in terms of the objects and operations at an office desk. Again the metaphor allows us to understand the more abstract domain (operations on computer files and directories) in terms of the less abstract, familiar operations of handling documents and folders on a physical desktop.[15]

However, further complexity can arise. "Is the *desktop metaphor* [a single metaphor] or an aggregate of many (file, folder, clipboard, etc.)?"[16] More importantly, is the *desktop metaphor* the best choice to bridge the "abstract domain" of the system and that of the operations familiar to the intelligence analyst?

Metaphor then, in the sense that it is employed in system design, goes well beyond a simplistic linguistic substitution. As noted by J.F. Sowa, "a metaphor does more than transfer a type label; it transfers an entire schema or cluster of schemata to a

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[14] *Webster's New World Dictionary of the American Language*, College Ed., 1968, under the term "metaphor."

[15] Werner Kuhn, "7±2 Questions and Answers About Metaphors For GIS Interfaces," in *Cognitive Aspects of Human-Computer Interaction for Geographic Information Systems* 83, ed. T.L. Nyerges and others (Dordrecht, The Netherlands: Kluwer Academic Publishers, 1995), 114.

[16] Werner Kuhn, 119.

new type."[17] This powerful concept suggests that the choice of metaphor is a critical component in human-computer interface design and plays an active role in shaping the representation of knowledge. An examination of the current desktop metaphor for "best cognitive fit" within the domain of intelligence analysis is indicated and is explored in this study.

A Critique of the Current Paradigm: The Desktop Metaphor. The term *desktop metaphor* is used to describe the current user interface for personal computers and most workstations that evolved from the research of Xerox PARC laboratories in the 1970s.[18] Popularized by Apple Computers initially, and then adopted by the Microsoft DOS/Windows personal computer environment, it has become the de-facto standard for interface design throughout private industry, and subsequently, the military. Based on leveraging the familiarity of traditional office functions, it was employed as a means for new users to transition from "paper documents and file folders" to their digital counterparts of word processing and file directories.

While a highly innovative, if not brilliant, step forward in popularizing the PC to a worldwide audience, substantial evidence exists that the thirty-years-old-plus desktop metaphor has passed beyond relevance. The current interface represents a generic, one-size-fits-all approach derived entirely from a business/office model and geared towards the novice user. This paradigm is market-driven and fails to take into account the

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[17] J.F. Sowa, *Conceptual Structures: Information Processing in Mind and Machine* (Reading, MA: Addison-Wesley Publishing Co., 1984), 270.

[18] Multiple and sometimes contradictory "histories" of the origin and development of graphical user interfaces (GUI), including what became to be known as the *desktop metaphor,* are readily available. Xerox PARC (Palo Alto Research Center) is generally credited with the first fielded design in the 1970s, (although commercially unsuccessful) which was later revived/adapted by Apple and others.

increasing sophistication of an entire generation of computer users that are not products of the traditional pre-automation environment and cannot be defined as "novice-class."

POSITIONING THE RESEARCH

This study was undertaken in an effort to question whether the current suite of PC-based tools (collectively termed the *PC Paradigm*) are truly suited to support the stated aims of the intelligence community. These aims include a renewed dedication to analytic rigor that advocates the use of structured methodologies, several of which that emphasize evidentiary and inferential techniques.

The pursuit of such "high-order analysis" relies heavily on visualization, mental modeling, and knowledge representations that have important implications in terms of human-computer interface and cognitive process. "The usability of such human-computer interfaces depends on how the cognitive abilities of the user are either facilitated or stressed by the interface."[19]

As pointed out in the opening section of this thesis, the role of Commercial-off-the-Shelf (COTS) technologies is tightly linked to this discussion. COTS approaches are specifically examined for their applicability to the problems faced by the intelligence analyst. This examination is informed by an interdisciplinary review of both theoretical and applied design considerations using widely-accepted models in various related fields.

[19] Kent L. Norman, *Interface Apparency and Manipulatability: Cognitive Gateways Through The Spatial Visualization Barrier In Computer-Based Technologies*, Monograph, University of Maryland (College Park, MD: N.p., n.d.) 2.

This study is unique in that it illuminates a growing body of literature that brings to bear diverse perspectives from disciplines outside the normal scope of the intelligence community, and seeks to provide a synthesis of multidisciplinary research.

ASSUMPTIONS

The Domain of Intelligence Analysis

This study is oriented towards the professional intelligence community and as such, certain assumptions will frame the discussion. First and foremost is an agreement upon the goals and intentions of intelligence analysis as set forth in the intelligence literature from the community's inception to the present day. While debate is certainly acknowledged and the nuances have been the subject of countless papers, articles, and theses, the general "philosophy" of the intelligence cycle has remained as a fundamental principle. Within this familiar cycle of "requirement," "collection," "production," and "dissemination" lies the implied task of *analysis* – the *raison d'etre* of our profession.

For the purposes of this paper, *analysis* will be assumed as the driving imperative and the *support of analysis* as the purpose of all tools (automated or not) employed in its pursuit. Further, for the sake of expediency and based on academic principle, the preferred method of performing analysis is grounded in the principles espoused by the

curriculum of the Joint Military Intelligence College, and encompassing the suggested guidance and models of MacEachin[20], Heuer[21], Toulmin[22], Schum[23], and Hughes.[24]

These models of critical thinking move beyond the simplistic and intuitive, representing high-order cognitive function and the ability to replicate and illustrate the analytical process. They include Analysis of Competing Hypotheses (ACH) methods, the use of evidence and inference, argumentation, and other techniques employing "imaginative and critical reasoning."[25] Acknowledging the background of the intended audience, it is expected that the reader is familiar with the intelligence domain and minimal time will be spent on elaborating on the theme except for cases of clarification.

The Applicability of Constructs Common to the Sciences

It is the author's belief that theoretical concepts that apply to what Kuhn[26] refers to as ""normal science" have application to the problems facing the intelligence community. Intelligence as a profession has much in common with the sciences; utilizing

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[20] Douglas J. MacEachin, former Deputy Director of Intelligence (1993-1996) was particularly noted for his strong beliefs in analytic process and critical thinking. MacEachin sought to incorporate tradecraft standards for analysts and advocated structured argumentation through "linchpin analysis." A brief, but informative assessment of the former DDI's impact is found in Heuer's *Psychology of Intelligence Analysis*, pp. xv-xvii, as cited in the bibliography.

[21] Richards J. Heuer, as cited in the bibliography.

[22] Stephen E. Toulmin, as cited in the bibliography.

[23] Dr. David A. Schum, Professor, George Mason University, as cited in the bibliography.

[24] Francis J. Hughes, Professor, Joint Military Intelligence College, as cited in the bibliography.

[25] Francis J. Hughes, *The Art and Science of the Process of Intelligence Analysis*, course material handout developed for the analysis curriculum (Washington, DC: Joint Military Intelligence College, September 2002): 2.

[26] Thomas S. Kuhn, 10.

both qualitative and quantitative methodologies, a belief in scientific method and the advocacy of the pursuit of excellence in research.

Intelligence analysis is inherently interdisciplinary and often draws upon knowledge and skills from multiple knowledge domains. Such cross-fertilization of ideas is to be encouraged and should be expanded upon to avoid the tendency to limit solution possibilities to those within immediate grasp. This paper seeks to offer a linkage to ideas and concepts that are usually found outside the normal scope of the intelligence analyst.

Intangibles

Intelligence analysis, cognitive science, and human-computer interface design have all been characterized as "art" as well as science. Discussion of theoretical and applied concepts in these and related fields must contend with sometimes fractious schools of thought and can descend into endless debate. Recognizing the potential for subjective division, every attempt has been made to remain on 'solid ground" and avoid overly controversial positions within the respective fields of research and instead to illustrate concepts with generally-accepted examples.

SCOPE CONSIDERATIONS

Synthesis, Reduction, and Focus

In attempting a multi-disciplinary fusion of research findings spanning a rich and sometimes contentious collection of sources, a certain amount of reductionism is required. The focus remains on showing how multiple lines of inquiry, particularly within the cognitive science and interface-design schools of thought, can reveal a

convergence of design theory that is directly applicable to analytic practice. This paper is not intended as an exhaustive treatment of each contributing field of study, but rather as an illumination of shortcomings in the accepted *PC Paradigm* and to suggest solutions based on grounded research that reside in areas of study outside the usual range of interest for the intelligence analyst.

On Advanced Graphics Workstations

It is acknowledged that specialized workstations, generally "high-end" and capable of sophisticated image manipulation have been in use within DoD for some time. Currently, these workstations are most widely found in the geospatial information systems (GIS) and imagery analysis (IMINT) sectors, although a very active R&D effort continues DoD-wide with extensive contractor involvement. Intriguing potential aside, the reality is that comparatively few members of the intelligence analysis community use such specialized workstations in their daily duties (GIS/IMINT workstation exception noted).

An excerpt from a U.S. Army-sponsored research project commissioned to prototype one such system[27] is illustrative of the pragmatics involved in the actual fielding:

> Although exceptionally good graphics capabilities are supported by Unix machines such as the Silicon Graphics, Inc. IRIS series, the relatively high price/performance ratios eliminated them from further consideration as potential hosts … we thus favored the Macintosh OS and DOS/Windows environments. Although the former provides superior graphics tools, we selected the latter

[27] Greg Zacharias and others, *VIEW: Visualization and Interactive Elicitation Workstation – A Tool For Representing the Commander's Mental Model of the Battlefield*, Monograph, U.S. Army Research Institute for the Behavioral and Social Sciences (Cambridge, MA: Charles River Analytics, December, 1996), 5.

> because of the much larger installed base…and the greater likelihood of integration/networking with existing Army systems.

In practical terms, advanced workstations are available and provide specialized tools to a certain *subset* of the analyst community, while the desktop PC and the laptop remain the primary tool for the majority. This study does not address the high-end, specialized workstation segment except in the cases of desirable design principles that generally apply.

On Specialized Commercial Software

As in the case of specialized workstations described above, a variety of commercial software packages are available to support visualization and data exploration. Often designed to augment complex quantitative datasets, popular examples include *Mathematica*™, *MatLab*™, and *Analytica*™,[28] among others.

Rather than characterizing these types of packages as contrafactual examples of the *PC Paradigm*, the author submits that such specialized packages were created in response to a recognized need for analytical support that was not being met by the existing product offerings in their respective research domains. Such a requirement is keenly felt within the field of intelligence analysis as well, and the lack of effective <u>fielded</u> solutions is evident.

[28] *Mathematica* is a trademark of Wolfram Research found at www.wolfram.com; *MatLab* is a trademark of Mathworks found at www.mathworks.com; *Analytica* is a trademark of Lumina Decision Systems, found at www.lumina.com.

On the Advanced Research and Development Activity (ARDA)

The need for revolutionary research programs within the intelligence community is recognized and sponsored by the *Advanced Research and Development Activity* (ARDA), located in Fort Meade, Maryland[29]. ARDA's focus on high-risk, high-payoff research is structured to leverage multi-disciplinary expertise against existing or emerging problems and assist the transfer of potential solutions to the IC technology centers.

In researching this study, the author has reviewed several proposals and presentations outlined in the workshop and program review notes for one of the ARDA projects known as the *Geospatial Intelligence Information Visualization* (GI²VIS) program.[30] Highly intriguing research initiatives are in progress that address such issues as visual metaphor, iconography approaches, tailorable visualizations, and other design concepts intended to take visualization support for the analyst to the next level.

This notable effort directly emphasizes the need for multidisciplinary (or *interdomain*) approaches such as are advocated in this study. The visionary research supported by ARDA, however, remains speculative and holds promise for the future. For the purposes of this thesis, an assessment of the many ARDA research projects remains outside the intended scope.

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[29] For more information, the ARDA web site can be accessed at http:// www.ic-arda.org. The characterization of the ARDA mission cited herein was derived from this unclassified site.

[30] Department of Defense, Advanced Research and Development Activity, *GI²VIS 12-Month Workshop Notes*, 31 October – 1 November 2001 (McLean, VA: The MITRE Corporation) and *GI²VIS Phase I Program Review*, 16-18 October 2002 (McLean, VA: The MITRE Corporation).

On Alternative Interfaces

Cutting-edge research continues on alternative interfaces designed to facilitate human computer interaction through non-traditional methods. These alternatives include Virtual Reality (VR), immersive techniques, haptic (sense of touch) interfaces, data sonification (use of sound context) and others. While such alternatives are intriguing, this study is not intended as a platform to champion a particular conceptual interface. A particularly thorough treatment of near-term and fielded alternate interfaces is found in the NATO study, *Visualisation of Massive Military* Datasets: Human Factors, Applications, and Technologies.[31]

The Data Overload Problem

The concept of data overload will be assumed as widespread and persistent. This well-documented phenomenon is not confined to the intelligence community, and is an active subject of research in all sectors. Proposed solutions to this problem are not discussed, but the impact on the analyst of the exponential increase in data streams is considered. This increase is particularly evident in the recent proliferation of sensor-types, including availability of commercial remote-sensing data, UAV platforms, and unattended devices.

[31] NATO, *Visualisation Study.*

THESIS RESEARCH OVERVIEW

Based on the interdisciplinary nature of this paper, an expanded literature review and discussion follows in Chapter 2. To facilitate the arrangement of diverse data the review has been presented in a series of ten sections that address the research question with applicable and relevant commentary arranged by general field of study or conceptual point of view. These sections include:

- A Discussion of Paradigm, Theory, and Scientific Endeavor
- A Look at the Current Model
- Intelligence Analysis as Cognitive Process
- Applicable Concepts of Psychology and Cognitive Science
- Visualization and Mental Models
- Tenets of Graphic Design
- Human-Computer Interface (HCI) Design Considerations
- European/NATO Perspective
- Department of Defense (DoD) Guidance
- Cognitive Task Analysis (CTA) Methodologies

Research methodology and findings are presented in Chapters 3 and 4, while conclusions and recommendations for future study comprise the final section, Chapter 5.

CHAPTER 2

A MULTI-DISCIPLINARY REVIEW: RELEVANT LITERATURE AND DISCUSSION

This review presents an exhaustive survey of cross-disciplinary literature that encompasses *applicable research* extant in the fields of intelligence analysis, cognitive science, data visualization, graphics design, and human-computer interface (HCI) design. While the available literature in multiple fields is considerable, a focused survey reveals key papers and texts that are particularly suited to address the issues that exist at this intersection of disciplines and necessitates a literature review of greater expanse than generally called for in studies that draw primarily from a single knowledge domain.

Valuable applicable data is sometimes fragmented, appearing in a wide range of both military and non-DoD publications and likely to escape notice by the analyst community. The intent is to illuminate important theoretical and applied research and achieve a synthesis among the disparate bodies of research. While effort has been made to present relevant research under appropriate categories as outlined below, the interdisciplinary nature of the material exhibits considerable overlap and often resists attempts at strict categorization. This is however, a desirable intersection, and serves to illustrate the interlocking and mutually supportive nature of the research.

A Discussion of Paradigm, Theory, and Scientific Endeavor

Any discussion of theoretical constructs, paradigms, and conceptualizations can easily encompass idealized and philosophical notions. These discussions, while

interesting, can stray from the focus of the subject at hand and as such, will be limited to bringing out those points with direct application.

Kuhn's discussion of paradigm[32] is widely referenced throughout the literature and is key to understanding how "worldview" influences cycles of scientific progress. This thesis considers Kuhn's definition of *normal science*[33] and his view of periodic cycles of revolutionary progress, as directly analogous to the workings of the intelligence community. Within the IC, "normal analysis" can be viewed as a collection of accepted practices interspersed with periods of rapid change. Drawing upon another model from the sciences, this fitful progress proceeds in a fashion not unlike that of the *punctuated equilibrium* theories advanced by Gould,[34], i.e. long periods of relative stasis punctuated with periods of rapid and dramatic upheaval and change. There is a general consensus that the events of September 11th, 2001 marked just such an epoch, and may serve as the driving imperative to further "paradigm shifts" within the IC.

When viewed in this manner, Kuhn's observations on mindset/worldview/ paradigm can offer insight into "intelligence crises" that seem to recur. One might well substitute the world "*intelligence*", as this author has done, in place of "*science*" in Kuhn's pronouncement below:[35]

> When … the profession can no longer evade anomalies that subvert the existing tradition of scientific [*intelligence*] practice – then begin the extraordinary investigations that lead the profession at last to a new set of commitments, a new

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[32] Thomas S. Kuhn, 23.

[33] Thomas S. Kuhn, 10. Kuhn defines *normal science* as "research firmly based upon one or more past scientific achievements, achievements that some particular scientific community acknowledges for a time as supplying the foundation for its further practice."

[34] Stephen Jay Gould, *The Structure of Evolutionary Theory* (Cambridge, MA: The Belknap Press of the Harvard University Press, 2002), 765-784.

[35] Thomas S. Kuhn, 6.

basis for the practice of science [*intelligence*]. The extraordinary episodes in which that shift of professional commitments occurs are the ones known … as scientific [*intelligence*] revolutions. They are the tradition-shattering complements to the tradition-bound activity of normal science [*intelligence practice*].

The relevance of paradigm, elaborately and eloquently set forth in Kuhn's text, cannot be overstated. Kuhn remarks that "[established viewpoints and preconceptions] … can operate as a sort of restriction [that can] bound the admissible solutions to theoretical problems."[36] In intelligence analysis, as in science, it is imperative that the "admissible solutions" remain "unbound" until either refuted or confirmed. Formalizing this process by requiring the representation of the reasoning chains involved in analysis is a primary goal of research and applications advocated by Schum, MacEachin, Heuer, Hughes, and others as illustrated below.

Dreyfuss points out that the "reigning conceptual framework implicitly guides research just as the perceptual field guides our perception of objects."[37] Without invoking the concept of paradigm explicitly, Dreyfuss makes note of the negative aspects of becoming attached or anchored to a particular systemic view by stating,

> that one must not become so fascinated with the formalized aspects of a subject that one forgets the significant questions which originally gave rise to the research, nor should one be so eager for experimental results that one continues to use old techniques just because they work, when they have ceased to lead to new insights.[38]

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[36] Thomas S. Kuhn, 39.

[37] Hubert L. Dreyfuss, *What Computers Still Can't Do: A Critique of Artificial Reason* (Cambridge, MA: The MIT Press, 1992): 279.

[38] Dreyfuss, 233.

This paper considers *paradigm conflict* to be a key contributing factor to visualization channeling that may restrict the solution sets available (or apparent to) the analyst.

A Look at the Current Model

> For many people, the desktop represents a permanent, perceptually valid contribution to computer interface design. 'Like many other brilliant ideas,' Steven Levy writes of the desktop model as it emerged from PARC, 'once introduced it is unimaginable to conceive of working without it.'
>
> David Gelernter, *Machine Beauty*

The ingrained familiarity of what is sometimes derisively termed the "WIMP" interface (Windows, Icons, Menus, Pointers), continues to undergird the current paradigm. Considerable debate exists however, on whether the *desktop metaphor* that ushered in the rapid acceptance of the personal computer remains relevant.

Genter and Nielsen point out that "although the use of metaphor may ease learning for the computer novice, it can also cripple the interface with irrelevant limitations and blind the designer to new [and more appropriate] paradigms."[39] David Gelernter characterizes such limitations as exhibiting the effect of *paradigm drag* which "comes in when the electronic version is cramped by the limitations of the physical one."[40] Gelernter further observes that entities such as *file*, *folder*, and *desktop* are "earthbound-metaphors, ... ideas [that] are patterned so closely on preexisting physical models that the software is seriously constrained."[41]

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[39] Don Gentner and Jakob Nielson, "The Anti-Mac Interface," *Communications of the ACM* 39, no. 8 (August 1996): 71.

[40] David Gelernter, *Machine Beauty: Elegance and the Heart of Technology* (New York: Basic Books, 1998), 89.

[41] Gelernter, 64.

The *desktop metaphor* and its office-based conceptual structure is not the sole source of concern. The familiar use of "windows" as a means of managing multiple streams of data creates a *cognitive loading effect* that must be taken into consideration. Multi-windowing environments, while common and indeed useful, place demands on the user to optimize the display configuration. When this effect is ignored as part of the design process, the end result often results in clutter and distraction rather than enhancing information display, as observed in the following cognitive study.[42]

> One pitfall is to rely on the flexibility of multi-windowing systems to substitute for detailed analysis of information display requirements. The premise is that users can call up and configure many views in parallel, tailoring the display to their particular needs at a given point in time. However, this strong reliance on the skills of users to configure displays optimally represents a failure of design. Handing off too much of this task to users creates extra data-management tasks that shift the burden of task analysis and display configuration onto users. The user's limited attention resources are shifted to the interface in order to identify desired data, navigate to the necessary location in the display space, and configure coordinated views. The CRT can become cluttered with windows, causing problems in determining where to focus attention and making it easy for the user to miss new events. These navigation and interface-management activities place high demands on user memory rather than capitalize on the interface as an external representation aid.
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> Similar observations are made by Medyckyj-Scott who notes that,
>
> "although multiple windows increase the perceived viewing space, they may not necessarily increase the visual scope if the user is unable to see a relationship which spans the display or is unable to locate which window holds pertinent data."[43]

In addition to the discussion of *desktop metaphor* and the windowing environment, a third aspect of the current paradigm will be examined -- the office-based software suite itself. Specialized software aside, the typical commercial software

[42] Emilie M. Roth and others, *Cognitive Engineering: Issues in User-Centered Systems Design*, Monograph, Roth Cognitive Engineering (Brookline, MA: N.p., 1994), 4-5.

[43] D. Medyckyj-Scott, "Visualization and Human-Computer Interaction in GIS," in *Visualization in Geographic Information Systems*, ed. Hilary M. Hearnshaw and David J. Unwin (New York: John Wiley and Sons, 1994), 205.

package consists of a suite of database, word processing, and spreadsheet applications. Microsoft Office™ is a popular and typical configuration.

The author contends that such software tools introduce an inherent cognitive influence that shapes the thinking of the user by channelizing or limiting "admissible solutions." To illustrate by means of a simplified analogy, the example of the rapid acceptance of the spreadsheet program as the near-universal model of financial and accounting analysis is offered.

Spreadsheet software was one of the early "killer app"[44] market successes that helped provide much of the momentum during the PC's introduction. The familiar column and row representation of data "cells" offered flexible attribute assignment and rapid recalculation and became the de-facto standard of financial analysis. One could safely assume that if asked to perform nearly any type of financial analysis today, a spreadsheet program would almost universally be consulted to array and compare the data.

At this point in the discussion, it could be argued that the spreadsheet model has *implicitly defined* how the financial analysis will be conducted and *explicitly defined* how the resultant answers will be represented to the user. Expressed in a different manner, the representation of the data and its variable relationships is determined by the spreadsheet, and thus shapes *the user's visualization of the dataset and its mental model.* The conceptualization is thereby *channelized* and delimited by the spreadsheet construct.

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[44] Bill Gates, *The Road Ahead* (New York: Viking/Penguin Group, 1995), 68-69. The term "killer application" (or more commonly "killer app") is widely used to connote a wildly successful product, generally referring to a commercial software application. Gates describes it as a "use of technology so attractive to consumers that it fuels market forces and makes an invention all but indispensable, even if it wasn't anticipated by the inventor." Early "killer apps" in the software realm included WordStar™, dBase™, and Visicalc™.

As noted by Roth and others[45], "it is a fundamental scientific finding that how a problem is represented affects the cognitive work that is needed to solve that problem, referred to as the *representation effect*." Further research on this effect, specifically in regards to intelligence problems, is warranted.

Despite the likelihood of "channelization," the value (and continued commercial success) of the spreadsheet is found in its particular suitability to the domain of finance and accounting. It is this *domain relevance* however, that is lacking in business-model tool sets when applied to the problems of intelligence analysis.

> Nobody would argue that an accounting program like Visicalc 'thinks' about business, but it is a vital tool *because of the clear and appropriate correspondence between its domain and the activities that generate the commercial world.* Another widespread example is 'word processing.' Its domain is the superficial stuff of language – letters and punctuation marks, words, sentences, and paragraphs. A 'word processor' does not understand language, but can be used to manipulate text structures that have meaning to those who create and read them. The impact comes not because the programs are 'smart' but because they let people operate effectively in a systematic domain that is relevant to human work.[46] (*italics mine*)

A discussion of relevant domain issues encountered within intelligence analysis is presented in the following section.

Intelligence Analysis as Cognitive Process

Although geared for the intelligence practitioner, the limits of discussion are outlined in the assumptions provided in Chapter 1. The intent is not to fully describe or debate the relative merits of analytical methodologies, but to introduce the recognized

[45] Emilie Roth and others, 6.

[46] Terry Winograd and Fernando Flores, *Understanding Computers and Cognition: A New Foundation For Design* (Norwood, NJ: Ablex Publishing Corporation, 1986), 175.

cognitive aspects of analysis that should be addressed during considerations of optimum design. This section introduces some of the key underpinnings in analytical thought, and examines the findings of a DoD study that specifically addresses cognitive processes in intelligence analysis. Finally, unique aspects of the intelligence domain that apply to the discussion are presented.

Data vs Analysis. Intelligence analysis is concerned with problem-solving, not merely the accumulation, manipulation, and presentation, of data. As noted by Grabo:

> "facts don't speak for themselves ... If the sole function of intelligence was to compile 'facts,' there would be little need for analysts of any type. The intelligence process would consist almost entirely of collection of raw data which would be evaluated for accuracy but then passed on without further comment or analysis to the policy official.[47]

Traditional reliance on order-of-battle summaries, comparative force assessments, weapon and equipment capabilities studies, and unit locations has often belied the contention that analysis is indeed more than data representation. It should be noted that it is not coincidental that our intelligence collection platforms are optimized to gather such information. *More importantly, the existing automated tools generally available to the analyst support just this type of data representation, while the analytic component is largely left unaided.*

The literature suggests that these different modes of intelligence analysis have long been recognized, even if not reflected in our available tool sets. Heuer distinguished between *data-driven analysis* and *concept-driven analysis*[48] as early as

[47] Cynthia M. Grabo, *Anticipating Surprise: Analysis for Strategic Warning*, (Washington, DC: Joint Military Intelligence College, December 2002), 133.

[48] Heuer, 59. Heuer mentions in a footnote on page 51 that this material originally appeared in *Studies in Intelligence* 23, no. 1 (Spring 1979) and also appeared in modified form in *The Bureaucrat* 8, 1979.

1979, and the findings of a contemporary DoD study (discussed below) share similar views.

A closer look at the works of Richards J. Heuer is particularly illustrative in this discussion. The mere fact that Heuer's collection of essays was entitled *The Psychology of Intelligence Analysis* is evidence of an early recognition of the centrality of cognitive factors in the conduct of what is collectively termed "intelligence analysis." The majority of the papers were written between 1978-1986 (although published in book form in 1999), and thus preceded the widespread introduction of the personal computer. His papers underscored the point that psychological and cognitive principles are intrinsically linked to intelligence analysis, and to its detriment, often overlooked. Convinced that "analytical aids" were necessary, Heuer observed that "tools and techniques that gear the analyst's mind to apply higher levels of critical thinking can substantially improve analysis on complex issues on which information is incomplete, ambiguous, and often deliberately distorted."[49]

One influential method of providing such tools to augment the critical thinking process is found in the works of Dr. David Schum.[50] A central figure in matters involving evidential and inferential techniques as applied to intelligence analysis, his two-volume work is an erudite treatise on the subject. It brings together the elements of jurisprudence, legal argumentation and classical logic into a comprehensive synthesis directed at aiding the intelligence analysis in hypothesis evaluation and the drawing of

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[49] Heuer, xviii.

[50] David A. Schum, *Evidence and Inference For The Intelligence Analyst*, Volumes 1 and 2, (Lanham, MD: University Press of America, Inc., 1987).

defensible conclusions. In agreement, Hughes[51] contends that the concept of *discovery-proof-choice* are the core activities of intelligence analysis.

Of particular interest, Schum poses the following conundrum: "Two astute, coherent, and knowledgeable analysts, having access to the same evidence, reach entirely different conclusions; how can this be so?"[52] The author then proposes an answer that suggests the fundamental importance of cognitive process and reliance on mental modeling:

> … as they begin to work on a given problem, they do so with different perspectives or frames of reference. Thus, their initial premises, hypotheses, or expectations may differ. Since this is so, they may easily differ in judgements about the relevance and weight of the evidence they both observe. Establishing the weight or force of evidence is a process that relies on the formation of analogies based on experience and precedent. Each of the analysts will have a different 'matrix' of experience to draw upon in this process. One analyst believes the weight of a certain evidence item, on a given hypothesis they both entertain, to be stronger than does the other analyst. In combining or aggregating the evidence, one analyst assumes that the evidence items are independent in their impact on the hypothesis; the other analyst sees an interesting and subtle pattern of non-independence among the evidence items.[53]

Working with "different perspectives or frames of reference" and relying on the "formation of analogies" to formulate their analysis are unequivocal indicators of high-level cognitive processes at work. For the analysts to "see patterns of non-independence," visualization and/or mental modeling occurs. Such observations suggest the recognition that cognitive models are clearly involved, even if not clearly understood.

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[51] F.J. Hughes, *The Art and Science*, 86-87. *Discovery* is the process where evidence is collected and hypotheses are generated and linked through arguments. *Proof* involves justifying an argument through the process of logical analysis. *Choice* is the process of deliberating about the arguments and making decisions with respect to their correctness or desirability.

[52] Schum, 17.

[53] Schum, 17.

One particularly applicable DoD study proposed just such a model as early as 1979. Targeted specifically to the domain of the intelligence analyst, an examination of this important research follows.

A Relevant Cognitive Model. *Cognitive Processes in Intelligence Analysis: A Descriptive Model and Review of the Literature*[54] published the findings of a project that sought to "develop a cognitive model that would provide a framework for the description of the mental processes used in intelligence analysis."[55] The researchers contended that *"while based ultimately on data, intelligence is actually created by the analyst. In other words, 'truth' is seldom hidden in the data; it is constructed by the analyst."*[56] This comment seems particularly striking, both for the period in which it was written, and for its applicability to the current environment.

In constructing their model, "It was assumed that a set of common analytic task processes exists that crosscuts the various intelligence disciplines such as SIGINT, IMINT, and HUMINT."[57] The conclusion seems decidedly "Heuerarian"[58]:

> *The most telling result of the research is the clear implication that intelligence analysis is conceptually driven as opposed to data driven.* What is critical is not just the data collected, but also what is added to those data in interpreting them via conceptual models in the analyst's store of knowledge. *The core functions of*

[54] Robert V. Katter and others, *Cognitive Processes in Intelligence Analysis: A Descriptive Model and Review of the Literature*, Technical Report 445 (Alexandria,VA: U.S. Army Research Institute for the Behavioral and Social Sciences, December 1979).

[55] Katter, 1-1.

[56] Katter, ix.

[57] Katter, 1-2.

[58] Note previous reference to Heuer's use of the *concept-driven/data-driven* phraseology. Although Heuer is not cited in the Katter report, Heuer's use of those precise terms in papers published in Spring 1979 would seem to precede that of Katter, if only slightly.

intelligence analysis involve the use of complex conceptual models. The ability to use such models is dependent upon individual capabilities as well as environmental or work setting variables."[59] [italics mine]

Chapter 2 of the Katter study describes their COMPARE/CONSTRUCT model, with refinements and relevant literature discussed in the document's Chapter 3.

In summarizing their cognitive model, the researchers concluded:

> [that] memory contents substantially determine the individual's automatic responses to, as well as [their] aware experience of, new information. ... Since memory contents provide a large portion of the information used in making many intelligence analysis interpretations and estimates, the information contents *modification cycle is an important concept for suggesting ways to improve* intelligence analysis.[60]

Keep in mind that such findings were derived in 1979, well before the arrival of the ubiquitous PC on every desktop, complete with INTELINK and various internet-based search engines. The author submits that the former analyst-reliance on "memory" as cited above, has been off-loaded to databases and online search results. The analyst today relies far less on human memory than on the "collective memory" residing online.

This discussion of Katter's study is provided to highlight two important points:

a. The crucial role of cognitive process *as a fundamental component of intelligence analysis* has been recognized for over two decades.

b. Such studies, rather than comprising elements of a core literature that informs system design for automated tools to support intelligence analysts, remain obscure and are not integrated into a coherent design methodology.

An applicable visualization reference model, accepted by NATO researchers, is examined below in the sub-section entitled *European/NATO Perspectives*. This tool,

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[59] Katter, 1-2.

[60] Katter, 2-16.

called the IST-005 Reference Model, is based on a sophisticated understanding of cognitive process and how it relates to the understanding of the entire *dataspace*.[61] This research presented in the NATO report clearly demonstrates their commitment to incorporate visualization technologies based firmly on cognitive design concepts.

Applicable Concepts of Psychology and Cognitive Science

One would be hard-pressed to find an area of study comprised of more divergent and controversial views than is found within discussions of psychology and cognitive science. Certainly, there is even a lack of consensus in what constitutes "cognitive science" in general, with various definitions encompassing aspects of cognitive psychology, philosophy, neuroscience, artificial intelligence research and more.

This thesis, however, will seek to limit time spent in such maelstroms of controversy, and instead will present a subset of terms and concepts that have a relatively widespread acceptance. These concepts can serve as important criteria to evaluate the effectiveness of the information displays under discussion. This is by no means an exhaustive list, but is intended to demonstrate the need for incorporating such considerations in the design phase of analytical tools.

Cognitive Ergonomics. In an effort to move theoretical discussion into practical application, the field of *cognitive ergonomics* "analyzes work in terms of cognitive representations and processes, and contributes to designing workplaces that elicit and

[61] NATO, *Visualisation Study*, 4. The aspect of the world that the human wants to understand and influence is represented inside the computer as a "Dataspace" accessible by computer processes ("Engines") that present their results through displays to the human's sensors (eyes, ears, touch...). From these displays, the human visualises the content of the dataspace, or rather, the aspect of the world the dataspace represents, and is able thereby to act effectively.

support reliable, effective, and satisfactory cognitive processing."[62] Reflecting the interdisciplinary theme that recurs repeatedly in the literature, cognitive ergonomics "overlaps with related disciplines such as human factors, applied psychology, organizational studies, and human-computer interaction."[63]

It is troubling, however, to note that a limited number of cognitive ergonomics research studies *within the domain of intelligence analysis* appear in a review of the literature. Notable exceptions include the previously cited Katter study[64], research work originating from the Ohio State University Cognitive Systems Engineering Laboratory (CSEL)[65], papers authored by Roth[66], the cited NATO Visualization of Massive Military Datasets Study,[67] and various ARDA initiatives.[68]

Congruency

The notion of *congruency* encompasses a range of overlapping concepts that are essential to ensuring and evaluating the suitability of an information display. Sometimes referred to as *conformity,* the concept "defines the degree of

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[62] MIT Encyclopedia of the Cognitive Sciences (MITECS), online edition, under the term "Cognitive Ergonomics." URL:< http://cognet.mit.edu/MITECS/Entry/cara>. Accessed 26 June 2003.

[63] MITECS, "Cognitive Ergonomics."

[64] Katter, 1.

[65] Emily S. Patterson and others, *Aiding The Intelligence Analyst In Situations Of Data Overload: A Simulation Study of Computer-Supported Inferential Analysis Under Data Overload*, Monograph, Report ERGO-CSEL-99-02, Ohio State University, Institute for Ergonomics (Columbus, OH: Cognitive Systems Engineering Laboratory, 1999). Key researchers include Patterson, Emilie M. Roth, and David D. Woods.

[66] Emilie M. Roth and others, *Cognitive Engineering*.

[67] NATO, *Visualisation Study*.

[68] The Advanced Research and Development Activity (ARDA) discussed in Chapter 1 sponsors a host of applicable research projects, some of which remain proprietary or unpublished.

correspondence between the mental model in the user's mind and the actual system presentation."[69] Stated in more familiar terms, it requires that "displays must match not only the user's purposes, but also the user's sensory and cognitive abilities."[70]

Several conceptual synonyms, with varying shades of meaning, are discussed throughout the literature, and can include "suitability for purpose," "fitness of purpose," and "cognitive fit." In some cases, the implications of *cognitive dissonance*, as advanced by Festinger[71], are included as part of the discussion.

An elaboration upon the idea of "cognitive fit" can assist the understanding of how it influences the suitability of a design:

> Cognitive Fit Theory states that a solution to a problem is 'an outcome of the relationship between the problem representation and problem solving tasks.' [Vessey, 1991]. The better the 'fit' is between these two constructs, the more effective and efficient the problem solving process. Therefore, when developing information visualizations, the developer must pay attention to the tasks performed by the decision-maker if the visualization is to be successful.[72]

Although termed in various ways, a critical assessment of "suitability" remains central. Bremer advances the notion of *verisimilitude*[73] to assess the validity of a model. "A model has verisimilitude to the degree that its behavior matches the behavior

[69] NATO, *Visualisation Study*, 59.

[70] NATO, *Visualisation Study*, iv.

[71] Leon Festinger, *A Theory of Cognitive Dissonance* (Stanford, CA: Stanford University Press, 1957): 12-13. Festinger states that "two elements are dissonant if, for one reason or another, they do not fit together. They may be inconsistent or contradictory."

[72] David P. Tegarden, "Business Information Visualization," *Communications of the Association For Information Systems* 1, Paper 4, electronic journal, January 1999: 11, URL:<http://cais.isworld.org>, under the keyword "Tegarden," accessed 10 January 2003.

[73] *Verisimilitude* as defined by Webster is the appearance or semblance of truth; likelihood; or probability.

of its referent system, and, other things being equal, the greater a model's verisimilitude, the more confidence we place in it."[74]

For the purpose of this thesis, a generalized definition will suffice to make the case for the concept's fundamental importance. Plainly stated, congruency should serve as a basic criteria to assess whether a display *facilitates or inhibits* the task it is claimed to support. There is scant evidence to suggest that such criteria are considered as design factors or evaluative measures in the current paradigm.

Domain Specificity / Domain Independence

Several fields of study, including cognitive science, recognize the concepts of *domain specificity* and *domain independence*. Fundamentally, it is agreed that "cognitive abilities are *domain-specific* to the extent that the mode of reasoning, structure of knowledge, and mechanisms for acquiring knowledge differ in important ways across distinct content areas."[75] In practical terms this means that the ways in which knowledge is acquired, understood, and expressed is unique to that domain, while *domain independence* conversely implies a model that is generally applicable across many domains.

Such principles are routinely used to inform design considerations. Within the intelligence domain, word processing software exhibits *domain independence*, whereas electronic light-table (ELT) software for the imagery analyst exhibits *domain specificity*.

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[74] Stuart A. Bremer, "Evaluating GLOBUS," in *The GLOBUS Model: Computer Simulation of Worldwide Political and Economic Developments*, ed. Stuart A. Bremer (Boulder, CO: Westview Press, 1987): 724.

[75] MITECS, "Domain Specificity."

While both concepts have appropriate applications, either decision has far-reaching implications for the end-user. One criticism of a domain specific design is that "its development effort cannot be amortized over several different systems."[76]

A domain independent approach, however, ensures the benefits of "economy of scale," as evidenced by most mass-marketed products, including the personal computer and its suite of business-based software. In the case of what is termed in this study as the *PC Paradigm*, domain independence is manifested as a generic, one-size-fits-all design optimized to maximize market share. While commercially impressive, such an approach fails to address the needs of those who require a domain-specific design.

Visualization and Mental Models

> Even though we navigate daily through a perceptual world of three spatial dimensions and reason occasionally about higher dimensional arenas with mathematical ease, the world portrayed on our information displays is caught up in the two-dimensionality of the endless flatlands of paper and video screen.
>
> Edward R. Tufte, Envisioning Information

The above quotation by Edward Tufte cogently captures the essence of a problem as central to the intelligence community as it is to graphics designers. The problems intelligence analysts face are rarely reducible to the simplistic "row and column/either-or" solutions often supported by spreadsheet and matrix-based tools. Instead, analysis examines concepts, relationships, and *multivariate data* by forming mental representations or *visualizations* of the problem.

It is important to emphasize that the term *visualization* in this context refers to a *process*, internalized within the user, and only in some cases expressed externally through a graphic, illustration, or computer display. The tendency to equate visualization to a

[76] Harold Thimbleby, *User Interface Design* (New York: ACM Press, 1990): 213.

visual display underscores the tool-centric paradigm in place and fosters the notion of visualization as a product or "deliverable" achieved through state-of-the-art information displays. "Visualization is not a data display, however ingenious. It is one route to understanding, another route being logical analysis."[77] Recognizing this key distinction, NATO researchers[78] have incorporated the concept into established design guidance, referred to as the IST-05 Reference Model:[79]

> The IST-05 Reference Model emphasizes that "Visualisation" does not refer to displays on computer screens, no matter how evocative and dramatic they may be. Screen displays are important to the visualisation process, in that a good display, by promoting a useful visualisation of the data being understood, provides a natural link between the human's understanding and those data. Engines and I/O devices are essential aspects of the visualisation support, and indeed are the only parts of the Reference Model subject to engineering design and modification. To design useful engines and devices, however, it is necessary that the designer understand the *human* process of visualisation.

The concept of visualization-as-cognitive-process seems to be broadly understood in the design community. Recurring themes across multiple disciplines are readily apparent and such convergences should indicate where design standardization and specification could begin on common ground. It is much less apparent that such design fundamentals are incorporated in currently-available tools for the analyst.

Elements of graphic design pertaining to this discussion are examined in the following section. Such explorations illustrate that the important link between cognitive

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[77] NATO, *Visualisation Study*, iii-iv.

[78] Presented and sponsored by the members of NATO Research Study Group IST-013/RTG-002 for the RTO (Research and Technology Organization) Information Systems Technology Panel (IST). The final report in its entirety is cited as NATO, *Visualisation Study.*

[79] NATO, *Visualisation Study*, 4.

process and information representation is appreciated even in non-systems-oriented fields of endeavor. As noted in *Envisioning Information*,[80]

> Escaping [two-dimensional] flatland and enriching the density of data displays are the essential tasks of information design. ... By giving the focus over to data rather than data-containers, these design strategies are transparent and self-effacing in character.

The characterization of current information displays as "data containers" seems particularly apt. Commitment to fundamental design principles that "transparently facilitate" the cognitive processes involved in visualization must be incorporated into the description of design requirements for meaningful analytic tools.

Tenets of Graphic Design

Fundamental principles of composition, color, balance, and line guide the pursuit of excellence in visual representations of all types. From the fine arts, to photography, to advertising, widely-accepted elements of design are utilized to most effectively "get the message across." While acknowledging the subjective nature of what constitutes "good design" within the arts, a school of thought has arisen surrounding the visual display of *information* as well. This subset of *"information display as tool"* is the focus of this study and is of central importance to the intelligence analyst. Fundamental design principles are available to guide the design of such tools, and the question remains, "Are the current information display technologies available to the analyst incorporating the optimal design elements?"

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[80] Edward R. Tufte, *Envisioning Information* (Cheshire, CT: Graphics Press, 1990): 33.

Among the most-respected proponents of excellence in information display is Edward R. Tufte whose works *The Visual Display of Quantitative Information* and *Envisoning Information* are considered classics in the field. Tufte suggests:[81]

> Excellence in … graphics consists of complex ideas communicated with clarity, precision, and efficiency. Graphical displays should:
>
> - Show the data.
> - Induce the viewer to think about the substance rather than about the methodology, graphic design, the technology of graphic production, or something else.
> - Avoid distorting what the data have to say.
> - Make large data sets coherent.
> - Encourage the eye to compare different pieces of data.
> - Reveal the data at several layers of detail, from a broad overview to the fine structure.
> - [emphasizing that] *…graphics reveal the data.*

Tufte would likely question whether the familiar refrain of information overload is actually the problem or merely symptomatic. To illustrate (simultaneously, though perhaps unintentionally, demonstrating that the data overload is not a new phenomenon) he quotes Richard Saul Wurman as stating in 1976 that "everyone spoke of an information overload, but what there was in fact was a *non-information overload.*"[82]

Indeed the display of *non-information*, variously characterized within the intelligence community as *noise*, *chaff*, *chatter*, or more broadly, *distractors*, is a vexing problem of current representations, but not one that should be considered insurmountable.

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[81] Edward R. Tufte, *The Visual Display of Quantitative Information* (Cheshire, CT: Graphics Press, 1983): 13.

[82] Tufte, *Visual Display*, 90.

Tufte observes:

> Confusion and clutter are failures of design, not attributes of information. And so the point is to find design strategies that reveal detail and complexity – rather than to fault the data for an excess of complication. Or, worse, to fault viewers for a lack of understanding.[83]

Apparently this dictum resonates as a fundamental truism, as Tufte concluded in his earlier text:

> What is sought in designs for the display of information is the clear portrayal of complexity. Not the complication of the simple; rather the task of the designer is to give visual access to the subtle and the difficult – that is, *the revelation of the complex.*[84] (*italics mine*)

Frankel[85] addresses the concept of easing the task of complexity representation by pragmatic approaches to image selection and presentation in the field of science. Pointing out that modern research is increasingly interdisciplinary in nature, the need for communicating findings and concepts to those outside of the immediate realm of the researcher's expertise is crucial. An apt parallel can be drawn to the modern intelligence analyst as they are increasingly called upon to provide the results of their analysis to a diverse and ever-widening audience of decision-makers, both military and civilian.

Envisioning Science provides technical guidance and specific applications suggestions for maximizing the information content of images, including photography and microscopy products, to diverse audiences. Important implications for the improvement of intelligence-related visual products can be inferred. Cautioning that immediate understanding is not always obvious and cannot be assumed, Frankel states

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[83] Tufte, *Envisioning*, 53.

[84] Tufte, *Visual Display*, 191.

[85] Felice Frankel, *Envisioning Science: The Design and Craft of the Science Image* (Cambridge, MA: The MIT Press, 2002).

that "creating order is the first step in making a successful image. ... You know what to look for and what to disregard, but the first-time viewer sees everything."[86] The author offers the following way to assist the viewer (or the analyst) in making connections:[87]

> Encouraging the viewer to compare the important component as it relates to something else helps to clarify what is essential and engages the viewer. ... When you include another form in the image, let's call it B, the viewer is able to make one of the following comparisons between components A and B:
>
> A looks like B
>
> A is different from B
>
> A has some relation to B
>
> A has nothing to do with B

The foregoing example illustrates that finding relevance in complex datasets is not a problem unique to the intelligence community. Solutions are being proposed, and techniques implemented, in other disciplines and fields of study that may have direct application to similar problems facing the IC.

Once again the importance of intersecting paradigms or "schools of thought" is evident. The design principles for optimizing information representation espoused by Tufte, Frankel and others are interwoven with research in the fields of cognitive science and mental modeling processes. The desired emphasis is on the goal of *information transference* and subsequent *knowledge formation* and not the technology involved. A critical examination of the current tools in use is necessary to determine if such design principles are truly driving the creation of new "analyst-assist products" and the improvements of existing tools and their features.

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[86] Frankel, 28-29.

[87] Frankel, 46-47.

Human-Computer Interface (HCI) Design Considerations

> The essential dilemma of a computer display: at every screen are two powerful information-processing capabilities, human and computer. Yet all communication between the two must pass through the low-resolution, narrow-band video display terminal, which chokes off fast, precise, and complex communication.
>
> Edward R. Tufte, *Envisioning Information*

The "dilemma" described above illustrates the challenge of creating an effective bridge between human and machine, commonly referred to as the human-computer interface, or more simply, HCI. Although the term "interface" is by no means limited to computing, for the purposes of this thesis, the following definition will be accepted:

> An interface is a describable structure through which a user interacts with a computer or task. 'Interface' is a noun that describes structures or mechanism, whereas 'interact' is a verb that designates process. 'Interaction' always is done through an 'interface' and neither can be completely described without reference to the other.[88]

A considerable literature exists in the field of human-computer interface design and this section is not intended as a primer on the subject. The discussion will however, bring forth key design concerns and introduce basic cognitive engineering objectives. An example using a National Aeronautics and Space Administration (NASA) scenario relevant to the intelligence domain is presented.

Norman offers a straightforward heuristic for evaluating an interface: "The usability of … human computer-computer interfaces depends on how the cognitive abilities of the user are either facilitated or stressed by the interface."[89] Norman's pronouncement brings important attention to the human aspect of HCI design.

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[88] NATO, *Visualisation Study*, 55.

[89] Norman, 2.

In many cases, the design effort is placed on the software engineering or "computer" side of "human-computer interface", while the "human" component is lacking or inadequate. *Cognitive engineering*, discussed below, seeks to address this imbalance. Sub-optimal design can occur when software-centric methods are exclusively employed. In such environments it is possible that "designers who are unaware of human factors knowledge about user interface design do not perceive a breakdown if one of the design guidelines is violated."[90] Roth and others caution that "the objective is to maximize the overall performance of this joint human-computer cognitive system, which is not always the same as maximizing the performance of the software when considered in isolation."[91]

<u>Design or Ad Hoc Creation</u>? There are those who question whether a structured design methodology is evident in all cases. System complexity, escalating customer requirements, lack of configuration management, and frequent changes in software maintenance personnel can all contribute to "feature creep" and "design-by-accumulation." Thimbleby observes:

> At present the best interactive systems are built partly by inspiration, possibly guided by formal considerations, but in large part by *ad hoc* creation. Many such accretions are details for handling special cases and are usually afterthoughts to the main thrust of design. ... Despite adherence to user-engineering principles, it is unlikely that a coherent system will result.[92]

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[90] Harold Reiterer, "User Interface Design Assistant," in *Computers As Assistants: A New Generation of Support Systems*, ed. Peter Hoschka (Mahwah,NJ: Lawrence Erlbaum Associates, Inc., 1996): 161.

[91] Roth and others, *Cognitive Engineering*, 9.

[92] Thimbleby, 201-202.

The prospect of creating "incoherent systems" through *ad hoc* design is sobering, but it is not the only potential pitfall. A phenomenon Thimbleby refers to as *intellectual sacrifice* has been observed to apparently remove rationality from the equation in some cases:

> Using a particular user interface causes people to become committed to it. It becomes 'right' and apparently better than competing systems even if [the competing systems] would have been right had they been used first. The users simply make a choice of axioms (and reasoning methods), then use them, then become irrevocably committed to their original choice – and it also becomes almost impossible to disabuse them of 'incorrect' aspects of the user interface design.[93]

A Cognitive Engineering Approach. The study entitled *Cognitive Engineering: issues in User-Centered Design*[94] presents a concise explanation of how a cognitive engineering approach centers on what the user is trying to achieve (the task) and the domain in which it is performed (domain specificity). The following summarized discussion and guidelines are particular applicable to the design environment that exists within the intelligence community:[95]

> The guiding tenet of cognitive engineering is that consideration of the users and the tasks they will be performing with the aid of a computer system should be central drivers for system design specification. HCI is not to be viewed as peripheral to the primary concern of software engineering. Instead a user centered, or practice-centered, system design approach is embraced in which the questions that drive design include the following:

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[93] Thimbleby, 342.

[94] Roth and others, *Cognitive Engineering*. The authors define *Cognitive Engineering* as an interdisciplinary approach to the development of principles, methods, tools, and techniques to guide the design of computerized systems intended to support human performance. ... The basic unit of analysis and design in cognitive engineering is a *cognitive system*.

[95] Roth and others, *Cognitive Engineering*, 2-3.

- What are the goals and constraints in the application domain?
- What range of tasks do domain practitioners perform?
- What strategies do they use to perform these tasks today?
- What factors contribute to task complexity?
- What tools can be provided to facilitate the work of domain practitioners and achieve their goals more effectively?

Such questions could serve as the basis for evaluative criteria when examining any proposed *or existing system* purported to augment intelligence analysis. Looking closely at the questions above, this cognitive engineering approach directly addresses many of the key issues of concern for the IC.

"Translating" the language of cognitive science terminology into terms and concepts more familiar to the analyst facilitates such an examination. A substitution of the phrase "*the intelligence field*" for "application domain," and "*intelligence analyst*" for "domain practitioner" clarifies the connection. Likewise, "strategies used to perform tasks" could become "*analytical methodologies.*" Factors that "contribute to task complexity" within the IC are well known and the subject of considerable discussion.[96] The intelligence domain must also contend with an environment characterized by *massive data*,[97] further indicating the need for a comprehensive design effort.

[96] Heuer. In *Psychology of Intelligence Analysis*, Heuer discusses numerous factors that contribute to the complexities of intelligence analysis including perceptual challenges, memory constraints, satisficing and premature closure, cognitive biases, information uncertainty and many others.

[97] Hughes, *The Art and Science*, 81. Hughes defines *massive data* as having multiple dimensions that may cause difficulty, some of which include volume or depth, heterogeneity or breadth, and complexity.

Cognitive Task Analysis (CTA) is one methodology that can be employed as part of such an approach to comprehensive cognitive engineering design, and will be introduced in a separate sub-section below.

HCI and Appropriate Metaphor. Any discussion of human-computer interface issues is closely linked to the concept of employing the appropriate *user interface metaphor* as discussed in Chapter 1. In the current PC Paradigm environment, the desktop metaphor continues to remain dominant for reasons that likely include some degree of *intellectual sacrifice* or "interface anchoring" as outlined above, as well as commercial market influence. Considerable evidence can be found, however, to suggest its suitability is in question throughout many information domains. Remarks from the civil sector include the observation that "while the desktop metaphor has become a very common one on some computer systems, it may be inappropriate for the town planner, utility manager or ecologist."[98]

Reasons for such "inappropriateness" may be grounded in the domain-general approach of the current paradigm in trying to be all things to all users. Appreciation for the fact that designers can consider a range of potential metaphors is not new, however, as *Fundamentals of Interactive Computer Graphics* pointed out in 1982:

> It may well be desirable that the conceptual model be similar to the concepts with which the user is already familiar. On the other hand, some other model may be more powerful and efficient. *The more adaptable the user community is to new ideas, the more the designer can opt for power over familiarity.*[99] (*italics mine*)

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[98] Medyckyj-Scott, 205.

[99] J.D. Foley and A. Van Dam, *Fundamentals of Interactive Computer Graphics* (Reading, MA: Addison-Wesley Publishing Co., 1982): 240.

A NASA Analogy. A comparison with the problems NASA has faced in planetary exploration provides a relevant analogy. Referring to the activities or tasks that are performed in this domain as *exploration behaviors*, McGreevy suggests "distilling" these behaviors and applying them to the design of user interfaces for exploration systems.[100]

As McGreevy points out, "this kind of distillation originally informed the desktop metaphor as well, but the behaviors of interest in that case were 'desktop,' paper-work-oriented behaviors."[101] The desktop metaphor is inappropriate, however, for the tasks and behaviors associated with planetary exploration. McGreevy's concern is with attempting to achieve a "spatial linkage with the environment being explored," and observes that "keystroke-oriented interactions, and point-and-click interactions with icons representing … documents, files, [and] paperwork tools" are quite inadequate.[102]

The dissonant condition described in McGreevy's example is a compelling example of the *non-congruency* between the functionality of the tool provided and the needs of the user working within a specific domain – a fundamental critique of the existing paradigm as discussed in this thesis.

European/NATO Perspective

Both the European Union and NATO are concerned with the consequences of rapid technology infusion. The following section summarizes key findings of particularly applicable documents.

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[100] M.W. McGreevy, "Virtual Reality and Planetary Exploration," in *Virtual Reality: Applications and Explorations*, ed. Alan Wexelblat (Cambridge, MA: Academic Press Professional, 1993): 181.

[101] McGreevy, 181.

[102] McGreevy, 182.

Relevant Views of the EU. Offering a pan-European perspective, the final report of the Advanced Science and Technology Policy Planning Network (ASTPP) was reviewed.[103]

The report noted a key challenge: "The production of highly sophisticated products makes increased demands on the science base, necessitating inter and trans-disciplinary research and the fusion of heterogeneous technological trajectories."[104]

Concern with such "trajectories" is well-placed as fragmented research efforts result in an uncoordinated sprawl of design solutions, each addressing only particular aspects of the larger problem. Recognizing the key influence of market forces in this process, the panel advocates a "variable geometry approach"[105] to ensure flexibility.

Such flexibility can help to avoid being swept before the "technological tide" and assist in mitigating the effects of what the report identifies as the *anticipation and control dilemma*[106], articulated as follows:

> At an early stage of technology development, the nature of the technology (and the articulation of interests) are still malleable – but it is unclear what the effects and impacts will be. By the time these become clear, the technology is entrenched and vested interests make it difficult to change the technology.[107]

Similiar observations appear to be a common lament. As noted by Davis and Medyckyj-Scott "introducing changes to the system, to improve interaction [after the

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[103] Kuhlmann and others. Contributors to the report included members from Germany, France, Greece, Finland, Great Britain, Portugal, Austria, The Netherlands, and Spain.

[104] Kuhlmann and others, 7.

[105] Kuhlmann and others, 15. "Policy has evolved from 'science policy,' to 'science and technology policy' and latterly to 'innovation policy,' with a corresponding shift in policy emphasis from 'science push' to 'market pull' and latterly to a realisation that 'variable geometry' policy mixes are needed to 'manage' complex 'innovation systems.'"

[106] Kuhlmann, 42.

[107] Kuhlmann, 42.

system is designed and built] can be very difficult due to technical and organisational inertia."[108] The ASTPP report underscores the pervasive nature of market influence and observes that "the recent economics and sociology of technology have traced the increasing path dependencies in technological development."[109] Restated, market and social forces are the drivers for technological development. Fitness-for purpose" design considerations are, not surprisingly, absent.

Unguided "technological trajectories" also create a "co-production of impacts," that even if unanticipated, may continue to exert influence far beyond the initial introduction of the product or feature. The study presents the "QWERTY keyboard of typewriters, but now also of computers, [as] a well-known example."[110]

NATO Perspectives. The North Atlantic Treaty Organization (NATO) relies on its Research and Technology Organization (RTO) for defense-related research and technology assessment.[111]

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[108] C. Davis and D. Medyckyj-Scott, "Introduction: The Importance of Human Factors," in *Visualization in Geographic Information Systems*, ed. Hilary M. Hearnshaw and David J. Unwin (New York: John Wiley and Sons, 1994): 191.

[109] Kuhlmann and others, 42.

[110] Kuhlmann and others, 42. The continued use of the familiar QWERTY keyboard layout is often used to demonstrate the "staying power" of an accepted paradigm long after its usefulness has expired. Although allegedly intended to slow the manual data-entry rate of early mechanical systems to avoid jammed keys, the veracity of the story is undetermined. In any event, while more efficient keyboard layouts are available, the original QWERTY design served to transition the dominant paradigm from the manual typewriter to the computer keyboard, where it remains dominant today.

[111] NATO, *Visualisation Study*, ii. RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote cooperative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. ... It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France.

Of particular note for the purposes of this thesis are three NATO RTO reports concerning visualization of massive data sets[112], commercial-off-the-shelf (COTS) integration issues[113], and perspectives on human factors in the 21st century.[114] These comprehensive studies offer a wealth of relevant information and a complete review of each document is beyond the scope of this study. Excerpted highlights of particularly relevant concepts are provided below.

The NATO Research Study Group "IST-013/RTG-002" has accepted a sophisticated visualization design model that incorporates cognitive process considerations, called the IST-005 Reference Model.[115] The model "emphasizes that 'visualisation' does not refer to displays on computer screens, no matter how evocative and dramatic they may be," and instead seeks to match displays to human sensory capabilities.[116] Discussions of the IFIP (International Federation for Information Processing) model[117] and Layered Protocol Theory[118] are presented.

A recent (2000) taxonomy for describing visualisation systems called *RM-Vis* is discussed.[119] Described as a "framework for the development of visualisation reference models that focuses on the application of visualisation solutions within particular domain

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112 NATO, *Visualisation Study.*

113 NATO, *COTS Study.*

114 North Atlantic Treaty Organization, *Human Factors in the 21st Century*, RTO-MP-77, AC/323(HFM-062)TP/38, (Neuilly-Sur-Seine Cedex, France: Research and Technology Organization, May 2002).

115 NATO, *Visualisation Study*, iv.

116 NATO, *Visualization Study*, 4.

117 NATO, *Visualisation Study*, 58.

118 NATO *Visualisation Study*, 61-64.

119 NATO *Visualisation Study*, 126.

contexts," the model "classifies visualisation applications in a three-dimensional space, with the dimensions of *domain context*, *visualisation approach*, and *descriptive aspects*."

Note that such tools for generating domain-specific reference models to build visualization systems are available and in use within the NATO research community. While not the only such effort (or model), the point to be made is that in the NATO examples cited, *design initiative* is being actively pursued rather than passive acceptance of commercially available solutions. An additional concern arises in questioning whether sufficient coordination is being made between the NATO and U.S. efforts in information display development. This is an issue that should concern "fitness-of-purpose" assessments for personal computer systems as well as specialized, high-end workstations.

Illustrating the fact that NATO recognizes the problem of "massive data" and intends to actively pursue visualization technologies as a solution, the RTO offers the following (excerpted) recommendations:[120]

> Section 10.4.1 General recommendations:
>
> Accelerate the development and deployment of information visualisation throughout NATO countries and PfP [Partnership for Peace] by promoting appropriate use of visualisation for improved information accessibility, operational, filtration, extraction and understanding. ...
>
> Stress the importance of evaluative testing as opposed to subjective "beauty contests" in determining the effectiveness of visualisation techniques.

The fundamental importance of *congruency* or "cognitive fit" as emphasized in this thesis is also apparent in the NATO design considerations, noting that "displays must match not only the user's purposes, but also the user's sensory and cognitive abilities."[121]

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[120] NATO, *Visualisation Study*, 134.

[121] NATO, *Visualisation Study*, iv.

Recommendations for developers include the following guidance:[122]

> Display requirements are different for analysis and for visualisation. Analysis is eased by an uncluttered display that allows the focal objects to stand out clearly and that illustrates their relationships, whereas visualisation generally requires copious context, possibly with the focal elements highlighted in some way.

In marked contrast, HCI design guidance offered in key U.S. Department of Defense Intelligence Information Program (DoDIIS) documents, reviewed below, suggests a strong COTS-product-driven influence rather than domain-specific design.

Department of Defense (DoD) Guidance

Conceptual design and idealism aside, a pragmatic examination of the present reality of PC-based systems employment within the Department of Defense (DoD) is necessary to provide balance. In doing so, it is readily apparent that both DoD and the private sector rely almost exclusively on commercial-off-the-shelf (COTS) acquisition for the introduction of new information technologies and upgrades to existing systems.

The subject of widespread COTS integration has been addressed as a matter of concern by NATO in a recent study.[123] One presenter characterized the driving mechanisms behind COTS acquisition thus:[124]

> COTS elements are produced for the civil marketplace, and evolve in the context of a fine balance across commercial issues of:
>
> - cost competiveness
> - customer expectation of quality

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[122] NATO, *Visualisation Study*, 133.

[123] NATO, *COTS Study*.

[124] Ian White, "Wrapping the COTS Dilemma", in NATO, *COTS Study*, 1-1.

- customer tolerance to shortfalls in quality
- lifetime in the marketplace
- commercial through-life support needs
- time to market
- mechanisms for maximizing a future market share

This marketplace-driven design methodology is predicated upon generic design that provides a one-size-fits all package that maximizes sales, yet fails to address specific user functionality requirements.

A second NATO presenter pointed out the tightly-linked relationship between the private and military sectors:[125]

> The 'ruthless pursuit of COTS' is increasing the penetration of unmodified COTS technology and standards in the military domain. Therefore, as the defence community becomes more reliant on off the shelf products and standards, it is increasingly a stakeholder in the results of the civil process.

Contrasting views that cast the COTS concept in a more favorable light were also expressed. After providing several examples of successful COTS integration, one U.S. presenter offered a pragmatic perspective: "the reality is that the significant investments made by the commercial sector in information technologies are orders of magnitude greater than the U.S. military can afford to drive or influence."[126] Seemingly expressed in a tone of resignation, this view seems to submit to the notion that the commercial information technologies sector operates as an autonomous juggernaut churning out "IT solutions" without regard to customer design requirements.

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[125] J.P. Thorlby, "The Coordinated Defence Role in Civil (Telecom) Standardisation," NATO, *COTS Study*, 6-1.

[126] James J. Barbarello and Walter Kasian, "United States Army Commercial Off-the-Shelf (COTS) Experience: The Promises and Realities," NATO, *COTS Study*, 5-9.

While perhaps an overly stark characterization, the COTS phenomenon fosters a "delegated-design mentality" that surrenders design initiative to the vendor, encouraging *design-by-proxy.* Under such conditions, the critical requirement for automated tools *designed* to support intelligence analysis, and incorporating the requisite cognitive, graphic design, and human-computer-interface factors, would occur only by fortuitous accident, if at all.

The foregoing discussion sheds light on the fact that COTS acquisition, even if inexorable and perhaps inevitable, continues to be a source of concern. If we are to accept COTS procurement, particularly in information technologies, as the current dominant paradigm, then a closer examination of specific DoD guidance regarding its integration is in order. In this discussion, the human-computer interface (HCI) is of particular concern. A brief review of two key DoD documents that specifically address HCI implementation guidance is revealing.

The *Department of Defense Intelligence Information System (DoDIIS) Profile*[127] is designed to "provide commonality and consistency among DoDIIS mission application development, integration, and site configuration activities."[128] Not intended to duplicate the *Joint Technical Architecture (JTA)* document (reviewed below), its intent is to "ensure systems in the DoDIIS are closely integrated and interoperable."[129]

Further, the profile "lists the JTA standards with which Government Off-the-Shelf (GOTS) software must be compliant [along with] Commercial Off-the-Shelf COTS

[127] Department of Defense, *Department of Defense Intelligence Information System (DoDIIS) Profile*, Version 4.1 (Washington, DC:GPO, November 2002). Cited hereafter as *DoDIIS Profile*.

[128] *DoDIIS Profile*, ii.

[129] *DoDIIS Profile*, ii.

products that comply with the appropriate JTA standards."[130] Section 2 addresses *service areas*, "high-level groupings of standards that comprise a common set of technical capabilities, such as User Interface standards."[131] Human Computer Interface Standards (HCI) are found in Section 2.4.[132]

A review of Section 2.4 reveals no entry for "DoDIIS Community-Specific Guidance" regarding GUI (graphical user interface) guides. Under "Mandated Standards," only the Microsoft publication, "Windows Interface Guidelines for Software Design" is offered – further evidence of the "delegated design principle" in action.

The *Joint Technical Architecture (JTA)* document "defines the service areas, interfaces, and standards applicable to all DoD systems, and its adoption is mandated for the management, development, and acquisition of new or improved systems throughout the DoD."[133] Divided into two sections, the JTA addresses JTA Core and JTA domain issues, including the domain for Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) where intelligence-related system standards are specified.

Specific excerpts from the Joint Technical Architecture document indicate a noted absence of interface design guidance, as follows:[134]

C4ISR.2.5 Human-Computer Interface Standards

C4ISR.2.5.1 Introduction

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[130] *DoDIIS Profile*, ii.

[131] *DoDIIS Profile*, 9.

[132] *DoDIIS Profile*, 33.

[133] Department of Defense, *Joint Technical Architecture* (JTA), Version 4.0 (Washington, DC: GPO, April 2001), iii. Cited hereafter as DoD, *Joint Technical Architecture*.

[134] DoD, *Joint Technical Architecture*, 96.

The human-computer interface standards and profiles described in this section facilitate interoperability between C4ISR systems through the use of standardized user interfaces, style guides, and symbology.

C4ISR.2.5.2 Mandated Standards
There are currently no mandated standards identified in this service area of the C4ISR domain.

C4ISR.2.5.3 Emerging Standards
There are currently no emerging standards identified in this service area of the C4ISR domain.

Cognitive Task Analysis (CTA) Methodologies

The previous discussions have sought to emphasize the importance of considering "cognitive process" as a fundamental design element in systems that operate within the domain of intelligence analysis. A wide range of assessment methodologies are available to the researcher or developer that can assist in achieving a better understanding of the cognitive aspects of a domain or a group of users. A very brief introduction to Cognitive Task Analysis (CTA) methodologies is provided to illustrate one such approach.

While many variations of the CTA concept can be employed, a commonality is generally found in attempting "to provide a formal specification of the knowledge and cognitive processing requirements for competent performance of domain tasks."[135] This can be achieved by concentrating on analysis of the domain itself, empirical approaches to understanding the tasks performed, or computer-based modeling. In practice, the three "idealized" approaches "should be viewed as complementary rather than as alternative methods [as] a mix of analytical and empirical techniques are required for a thorough cognitive task analysis."[136]

[135] Roth and others, *Cognitive Engineering*, 15.

[136] Roth and others, *Cognitive Engineering*, 16.

Numerous studies, many of which are cited throughout this thesis, clearly conclude that the choice of metaphor is a critical component in human-computer interface design and plays an active role in shaping the representation of knowledge. It has been pointed out that the choice of an inappropriate metaphor can "cripple the interface with irrelevant limitations and blind the designer to new [and more appropriate] paradigms."[149] Further, the research suggests that domain relevance is lacking in business-model tool sets when applied to the problems of intelligence analysis.

The negative effects of the *PC Paradigm* have evolved from a COTS-driven product-oriented approach and represents continued extensions of the desktop metaphor to domains well outside its original design intent. The current paradigm is not derived from cognitive ergonomic requirements unique to intelligence analysis, nor does it support the analytical methodologies widely regarded as "best practices" within the field.

These conclusions are based in part on the following points that were illuminated during the multidisciplinary assessment.

1. The author contends that this near-exclusive reliance on COTS technologies is based on market-driven, commercial product solutions rather than a "domain specific" system design that is optimized to support intelligence analysis. The COTS acquisition model is a *design-by-proxy* approach that has surrendered design initiative to the vendor. Domain independence is manifested as a generic, one-size-fits-all design approach optimized to reach the widest possible audience. While commercially impressive, such an approach fails to address the needs of those who require a domain-specific design.

2. To ensure suitability, a more effective approach is indicated by basing acquisition and development decisions on design principles that take basic cognitive

[149] Gentner and Nielson, 71.

A comprehensive articulation of the cognitive demands involved in intelligence analysis will be required for establishing an effective design specification that addresses the concerns of *domain specificity* and *information display congruency* as outlined in this thesis. Cognitive Task Analysis, in one or all of its many possible implementations, is offered as a promising approach.[137]

[137] A particularly useful reference for further information concerning Cognitive Task Analysis can be found online at CTA Resource, located at URL:<http://www.ctaresource.com/>.

CHAPTER 3

METHODOLOGY: THE GROUNDED THEORY MODEL

A grounded theory approach, based on Leedy's model[138], was followed in the structure of this study. This methodology is particularly well suited "when all of the concepts pertaining to a given phenomenon have not yet been identified, at least not in this population or place; or [when] the relationships between the concepts are poorly understood or conceptually underdeveloped."[139] Such an approach was selected to illustrate the *conceptual density* of this multidisciplinary study and explore important linkages through the use of *theoretical sampling.*[140]

Leedy's depiction of the suitability of a grounded theory approach, provided above, is especially apt for the purposes of this thesis. In examining the research question, it quickly became evident that many of the relevant concepts *and their relationships* appear to fit the description of being poorly understood or insufficiently developed within the "population or place" of the intelligence domain. This has had the effect of creating "conceptual islands" of theory that often exist in relative isolation within their respective fields and has lacked a coordinated synthesis as applied to intelligence problems.

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[138] Paul D. Leedy, *Practical Research: Planning and Design*, 6th ed. (Upper Saddle River, NJ: Merrill Prentice Hall, 1997): 162-165.

[139] Leedy, 163.

[140] Leedy, 164.

Rather than relying upon a limited or narrowly-defined body of evidence, a "broad and deep" approach was utilized. Identifying commonality in related, but disparate, theoretical and applied techniques thus allowed a convergence of interlocking themes to emerge.

The research sought to capture and distill the relevant findings of diverse sources and perspectives comprising case studies, research proposals, interview compilations, journal articles, published and unpublished papers, related theses, proposed and fielded models, and product literature. Balance was enhanced by including the views derived from academia, private industry, commercial sources, and Department of Defense research studies. Both U.S. and foreign perspectives were considered and evaluated.

Special emphasis was placed on DoD-related studies that explored cognitive aspects relating to the intelligence domain such as the primary research conducted by Patterson, Roth and Woods[141], and NATO-sponsored research in visualization of massive military datasets.[142]

Chapter 2 documents the wide-ranging survey that was required to identify and "pull together" the disparate "islands" of theory and practice that are openly available, yet often "buried" in the literature of their respective fields of interest. The author's contention is that a unified or coordinated approach to incorporating such design factors into our intelligence systems is non-existent, undermining the analytical effort.

The research methodology was focused on presenting a logical progression that was designed to flow in the following manner:

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[141] The study cited as "Roth and others, *Cognitive Engineering*," and *Aiding the Intelligence Analyst in Situations of Data Overload: A Simulation Study of Computer-Supported Inferential Analysis Under Data Overload by Patterson*, Roth, and Woods (cited previously) were particularly useful.

[142] NATO, *Visualisation Study*.

a. *First, examine and characterize the current tool available.*
(Existing paradigm, COTS influence, desktop metaphor)

b. *Second, examine the domain of interest in which the tool is applied.*
(Specifically, the domain of intelligence analysis).

c. *Third, examine the relevant fields of study that directly influence the tool and point out critical linkages where they occur.*
(Cognitive science, graphics design, human-computer interface)

d. *Fourth, examine the incorporation of such principles into existing design guidance.*
(Published DoD guidance and NATO perspectives)

e. The final category, *Cognitive Task Analysis Methodologies*, concludes the discussion of concepts by introducing a potential solution to address shortcomings and design concerns such as those raised in the thesis.

In conducting the research, certain evaluative criteria were used to ascertain whether a deleterious effect on analysis could be anticipated or expected. By examining the theoretical and conceptual principles that guide generally-accepted design, such an assessment could identify where discontinuity or design conflict may occur. Within this thesis, the following criteria were used to indicate the potential for the current personal computer environment to function as an analysis inhibitor:

- Dissatisfaction with the current paradigm.
- Evidence to suggest that analyst tasks may be inadequately supported.
- Evidence to suggest that the current paradigm appears to violate or ignore accepted guidelines within cognitive science, human-computer interface (HCI) and graphic design.
- Evidence that *congruency issues* may be apparent.

The complexities of handling a multidisciplinary review was managed by arranging sources into the following ten subjects or "fields of study" categories that facilitated the evaluation of applicability and relevance.

- A Discussion of Paradigm, Theory, and Scientific Endeavor
- A Look at the Current Model
- Intelligence Analysis as Cognitive Process
- Applicable Concepts of Psychology and Cognitive Science
- Visualization and Mental Models
- Tenets of Graphic Design
- Human-Computer Interface (HCI) Design Considerations
- European/NATO Perspective
- Department of Defense (DoD) Guidance
- Cognitive Task Analysis (CTA) Methodologies

CHAPTER 4

FINDINGS

As a qualitative study, the research explored a range of related fields and sub-disciplines, identifying conceptual, theoretical, and practical linkages that appertain to the research question. To assist in demonstrating the relevance of apparent linkages and where they seemed to occur, the research question is re-stated as follows:

Could the current personal computer environment (characterized as the PC Paradigm) function as an analysis inhibitor, rather than as a tool to facilitate analysis?

By examining this question in the context of the various "fields of study" categories outlined in Chapter 3 (Methodology), the research illuminated areas where the *PC Paradigm environment*, even theoretically, may indeed foster conditions detrimental to analysis. Key findings of this assessment are presented below. Discussion and conclusions drawn from such observations are reserved for the following chapter.

Key Findings

Congruency or "Fitness-of-Purpose" Considerations. The increasing sophistication of intelligence analysis methodologies requires tools that support high-level cognitive processes such as inferential reasoning and visualization of complex or "massive" data. The existing PC-based systems utilize a business-model created for a

general-purpose commercial market, employing a *desktop metaphor* (office-based) user-interface. A fundamental paradigm conflict is suggested between the requirements of the analytic process and the limitations imposed by the desktop metaphor.

The Presence of Conceptual Islands. Significant and relevant research has been conducted, and is ongoing, in many fields that lie outside the normal purview of the intelligence community. The literature is replete with studies that remain isolated in specialized domains although cross-field application is evident. Such observations point to a review of the design approaches, as suggested below.

Interdisciplinary Design Approaches Required. Cognitive studies cited in the thesis suggest that the process of intelligence analysis is considerably influenced by information representation, mental modeling, and visualization. Even though this appears to be a fundamental understanding, a systematic or coordinated effort to synthesize these generally-accepted concepts into application design guidance appears to be lacking.

COTS Influence. The role of Commercial-Off-The-Shelf (COTS) technology acquisition is tightly linked to the discussion of tool suitability and its influence cannot be discounted. Attempts to assess whether the current paradigm inhibits or facilitates the intended purpose of intelligence analysis return in circular fashion to the origin of the tool and the design criteria (or the absence of design criteria) that informed its development.

Proactive NATO Efforts. NATO research[143] indicates a solid appreciation for incorporating cognitive principles into defense-related information display design and have adopted cognitive reference models. Additionally, NATO studies have expressed concern on the pervasive and potentially negative aspects of continued COTS technology acquisition.[144] The level of coordination between NATO and U.S. design initiatives was not accessed.

Minimal DoD Guidance. In two key technical architecture documents,[145] little or no design guidance is offered in regards to human-computer interface issues. Rather than domain-specific concerns (i.e. intelligence analysis) driving interface requirements, commercial standards are adopted.

A Tangential Finding: Issues of Ontology[146]

This thesis did not undertake an examination of ontological issues or related topics of taxonomy and lexicon development. It became apparent during the research however, that the choice of appropriate metaphor candidates and consequent interface design relies heavily on a common understanding between the user and the developer of *domain concepts* and *conceptual relationships* – both issues of ontology.

A key detractor to a better understanding of the cognitive processes involved within intelligence analysis is the lack of an accepted ontological schema within the IC

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143 NATO, *Visualisation Study.*

144 NATO, *COTS Study.*

145 *DoDIIS Profile* and DoD, *Joint Technical Architecture.*

146 Sowa, 294. Sowa defines an *ontology* as resulting from a conceptual analysis whereby a "precise, formalizable catalog of concepts, relations, facts, and principles" is created.

itself. Such an ontology is essential in defining terms and conceptual relationships that provide the necessary "lattice-work" to facilitate cognitive mapping of the domain. The lack of an accepted ontology complicates development of standardized icon-sets and the creation of shared metaphors. Both are fundamental tasks in designing a user-interface in any domain. The domain of intelligence analysis is no exception.[147]

[147] Promising research in ontological design, with specific application to the intelligence community, is ongoing. A partial list of involved organizations include the Defense Advanced Research Projects Agency (DARPA), the Advanced Research and Development Activity (ARDA), and the Advanced Analysis Lab at NSA.

CHAPTER 5

SUMMARY /CONCLUSIONS / RECOMMENDATIONS

SUMMARY

The intelligence cycle, whether depicted in classic circular flow or as an iterative, looping model, depends on the *analytical process* at its core. Even with the widespread use of automated systems, this task currently remains a mental process, performed by the intelligence analyst. While such systems greatly facilitate other aspects of the intelligence cycle, particularly in collection and dissemination, *analysis* relies on an interplay of cognitive factors that have yet to be replicated in fielded computer-based tools. The complexity of the problem is described in a recent study.[148]

> Sometimes developers believe that shifting the task to a computer somehow makes the cognitive challenges of focusing in on the relevant subset disappear. In fact, all finite cognitive processors face this challenge, whether they are an individual, a machine agent, a human-machine ensemble, or a team of people. It always takes cognitive work to find the significance in data.

In an effort to augment the analyst's workload with current technological tools, the Department of Defense has adopted the industry-standard personal computer as a common solution. This has been achieved by relying on Commercial-Off-The-Shelf (COTS) acquisition as the primary means to introduce and upgrade computer technologies throughout the military.

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[148] Patterson and others, *Aiding the Intelligence Analyst*, 7.

In adopting this approach, the personal computer, or "PC," has become a de-facto standard, along with its commercial, business-model design. Within the thesis, this common, and widely-accepted desktop computer environment is defined as the *PC Paradigm*. The definition encompasses the PC's typical office-suite software, the information display, and the use of the *desktop metaphor* as the user-interface.

The research question inspired by the apparent dominance of the PC Paradigm was stated as: "*Could the personal computer environment (characterized as the PC Paradigm) function as an analysis inhibitor, rather than a tool to facilitate analysis?*"

This question was assessed by conducting a multidisciplinary exploration of related fields of study, including the areas of cognitive science, graphic design, and human-computer interface (HCI) considerations, along with a review of NATO and DoD design guidance on the subject of HCI design. This expansive review revealed significant intersections in design philosophy, applicable models, and concepts that indicated that the cognitive aspects of information displays are critical design considerations in determining how information is interpreted by the user. The concept of *congruency* or conformity was established as an important criteria in determining whether an information display maintained a "fitness-of-purpose." Simply stated, does the tool facilitate or inhibit the work it is designed to assist?

Key findings suggested that the reliance on COTS equipment has significant implications that are tightly linked to the discussions of the personal computer as a tool for intelligence analysis. Specifically, the commercial design of the PC facilitates its mass-market distribution but does not address the domain-specific requirements of the intelligence community.

Several research studies, including NATO research and DoD-sponsored projects, underscored the critical importance of considering cognitive design principles in the development of information display and visualization tools. A lack of DoD guidance in such matters was apparent however, in the technical architecture documents reviewed.

CONCLUSIONS

Intelligence analysis, as a profession, is inherently interdisciplinary and often draws upon knowledge and skills from multiple knowledge domains. Such cross-fertilization of ideas is to be encouraged and should be expanded upon to avoid the tendency to limit solution possibilities to those within immediate grasp. This research has sought to offer a linkage to ideas and concepts that are usually found outside the normal scope of the intelligence analyst. Potential answers to the research question were believed to be found at the intersection of several fields of study (or domains), each sharing an overlapping influence on some aspect of the question.

The results of the thesis research indicate that the potential for inhibited analysis exists within the currently accepted PC Paradigm. It is the author's contention that the industry-standard PC environment, and its *desktop metaphor*, are ill-suited for the task of intelligence analysis. A fundamental difference exists between *data representation* and *analysis*, with the former merely retrieving and arraying the data, while the latter represents human cognitive processes. The current tools of the PC Paradigm support the tasks of retrieval, representation, and dissemination, while the process of analysis remains largely unaided.

engineering considerations into account. The following questions are examples of the type of elicitation required to define the *domain specificity* required:

- What are the goals and constraints of the intelligence analysis domain?
- What range of tasks do the analysts perform?
- What analytical methodologies do they use?
- What factors contribute to analytical complexity?

3. The emphasis should be placed on *process and goal* and not *product or tool.* The desired emphasis is on the goal of *information transference* and subsequent *knowledge formation* and not on the technology involved

4. Congruency should serve as a basic criteria to assess whether a display facilitates or inhibits the task it is claimed to support. There is scant evidence to suggest that such criteria are considered as design factors or evaluative measures in the current paradigm. The concept of visualization as a cognitive process seems to be broadly understood in the design community, but such an appreciation seems less evident in the tools currently available to support intelligence analysis.

5. The crucial role of cognitive process as a fundamental component of intelligence analysis has been recognized for over two decades. Previous studies, rather than comprising elements of a core literature that informs system design for automated tools to support intelligence analysis, remain obscure and are not integrated into a coherent design methodology

6. NATO research endorses proactive design rather than passive acceptance of COTS technologies and has accepted cognitive reference models to inform the

development process. In contrast, DoD guidance is minimal and specifically states within the *Joint Technical Architecture* document that:

> "There are currently no mandated (or emerging) standards identified [in human-computer interface standards within] the C4ISR domain."[150]

It is significant to note with particular emphasis the specific phraseology of this excerpted passage, "*currently no mandated or emerging standards.*"

7. Other domains (including NASA examples and others) have rejected or expressed dissatisfaction with the *desktop metaphor.* Numerous examples exist in the literature that argue for a replacement of the dominant office-based desktop metaphor on the basis of its unsuitability and lack of domain specificity in their respective fields of endeavor.

RECOMMENDATIONS AND OPPORTUNITIES FOR FUTURE STUDY

Configuration Management for Cognitive Systems

A centralized means of ensuring "cognitive systems configuration management" is recommended to facilitate design oversight. Presently, promising research and development activity is undertaken largely in isolation resulting in a fragmented, uncoordinated effort that fails to identify and capture "best practices" in systems design.

[150] DoD *Joint Technical Architecture*, 96.

Further Exploration of CTA Methods

Cognitive Task Analysis methods were reviewed as a promising tool to assist in modeling the cognitive environment within the intelligence domain. Such structured methodologies could potentially provide the "verifiable and replicable" data that is missing within many qualitative assessments. Cognitive Task Analysis (CTA) is an umbrella term that encompasses a wide range of potential tools and evaluative concepts that has only been introduced here in minimal depth. Further research that incorporates CTA methodologies or evaluates their utility in addressing IC issues is warranted for future studies.

Increased Ontology Development Within The IC

The issue of ontology and the requirement for its articulation as a matter of interface design was mentioned in Chapter 4 as a "tangential finding." In the author's opinion, it is likely that bringing the entire "intelligence community" *in toto* under a single ontological umbrella is overly ambitious. A more pragmatic goal would perhaps be achieving a consensus or "baseline agreement" as a starting point within the individual sub-disciplines such as IMINT, SIGINT, HUMINT, MASINT. Until a minimal level of "lexical consistency" is reached, efforts to optimize a comprehensive design will likely remain fragmented, unfocused, and counterproductive.

Visualization Implications for Imagery Analysis

Fischbein's observation that " a visual image not only organizes the data at hand in meaningful structures, but is also an important factor guiding the analytical development of a solution"[151] is particularly revealing.

In the case of imagery analysis, the "data at hand" are already present in visual form – it *is* visual data. For electro-optical (EO) imagery, the data closely approximates a *literal model*; a visual wavelength representation of the target as it would appear monochromatically. Other sensors (IR, radar, MSI) represent non-visible wavelength depictions and are therefore figurative or *non-literal models* of the scene constructed of the spectral building blocks inherent to that sensor. In a very real sense, imagery products of all types are therefore *visualizations* in their own right, consisting of *families of literal and non-literal models*. This would suggest that any automated system approach to augment imagery analysis may involve "visualizations *of* visualizations" at the fundamental or cognitive level. Additional research to further investigate this contention may prove rewarding.

Towards A New Vision

A final comment in regards to future direction is offered. Wexelblat has pointed out that an article originally appearing in Byte magazine in 1992 suggested that "research from many fields is being synthesized to create a design philosophy of information environments."[152] While an intriguing possibility, the literature offers little

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[151] Fischbein, 104.

[152] Charles Grantham, "Visualization of Information Flows: Virtual Reality as an Organizational Modeling Technique," in *Virtual Reality: Applications and Explorations*, ed. Alan Wexelblat (Cambridge, MA: Academic Press Professional, 1993): 220.

evidence that such a synthesis has yet occurred. Instead, research efforts often remain fragmented, and can often be characterized as in the following excerpt from a recent NATO study:

> We have accumulated a lot of lessons learned, rules of thumb, best practices, and ways to avoid pits into which we have already fallen. However, the half-life of these lessons from the past will continue to decline at the same (accelerating) pace as that of computer technology. The only solution will be to design [automated support systems] based on a coherent, human-centered philosophy.[153]

The renewed pursuit of the coordinated "design philosophy of information environments" remains a worthy, and elusive, goal and should receive sustained support.

Cited research studies indicate that both the EU and NATO have made proactive steps to structure design initiatives that take such considerations into account early in the design process. Within the U.S., The Advanced Research and Development Activity (ARDA) is an important example of a forward-looking approach that emphasizes analytic process over off-the-shelf solutions. A broad reevaluation of whether a COTS-centric approach is fundamentally incompatible with efforts to create a coherent design philosophy appears to be warranted.

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[153] Sandra G. Hart, "Human Factors Directions For Civil Aviation," in North Atlantic Treaty Organization, *Human Factors*, 9-12 to 9-13.

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